MINISTRY OF WATER AND IRRIGATION

Water Resource Policy Support
Water Reuse Component

The "mixing point" in the Jordan Valley

STORAGE, CONVEYANCE & BLENDING, AND ANALYSIS OF SCENARIOS FOR WATER REUSE MANAGEMENT IN THE AMMAN-ZARQA BASIN

FINAL DRAFT

April, 2001

(Replaces in full the drafts of January 2001 and July 2000)

The Water Resource Policy Support activity is supported by
The United States Agency for International Development (USAID) through a
Contract with Associates in Rural Development Inc.(ARD):
USAID/ARD Contract No. LAG-I-00-99-00018-00, Delivery Order No. 800

TABLE OF CONTENTS

Appendix A –	Reclaimed Water Allocation Model (RWAM) – Technical Reference
Appendix B –	Reclaimed Water Allocation Model (RWAM) – Users Guide
Appendix C -	Water Quality Sampling & Data Reduction – Technical Note
Appendix D -	Preliminary Scenarios (Scenario Groups A & B) and Model Output
Appendix E -	Working Scenarios (Scenario Group C) Model Output
Appendix F -	Microbiological contamination in Wadi Zarqa – Technical Note
Appendix G -	RWAM-AZB Water Quality Results from Scenario C1-C3

ABBREVIATIONS

ARD	Associates in Rural Development
AZB	Amman-Zarqa Basin
BMP	Best Management Practices
BOD_5	Biochemical Oxygen Demand, Five Day
COD	Chemical Oxygen Demand
DA	Development Area
DO	Dissolved Oxygen
ECC	Economic Consultative Council
FCC	Fecal Coliform Count
GAP	Good Agricultural Practices
GIS	Geographic Information System
GPS	Global Positioning System
GTZ	German Technical Cooperation
HL	Highlands
HRZ	Hashemite-Rusefieh-Zarqa area
IAS	Irrigation Advisory Service
IRG	International Resources Group
JICA	Japanese International Cooperation Agency
JV	Jordan Valley
JVA	Jordan Valley Authority
Km^2	Square Kilometers
KTR	King Talal Reservoir
LEMA	Lyonaise des Eaux Management-Amman
LIMS	Laboratory Information Management System
m^3	Cubic meter
M&I	Municipal and Industrial
MCM	Million cubic meters
MOA	Ministry of Agriculture
MOH	Ministry of Health
MWI	Ministry of Water and Irrigation
NCARTT	National Center for Agriculture Research and Technology Transfer
NIR	Net Irrigation Requirements
NPW	Net Present Worth
NRA	Natural Resources Authority
RA	Rapid Appraisal
RS	Remote Sensing
SO	Stage Office
SS	Suspended Solids
TDS	Total Dissolved Solids
TO	Task Order
UFW	Unaccounted for Water
USAID	United States Agency for International Development
WAJ	Water Authority of Jordan
WRPS	Water Resources Policy Support
WSP	Waste Stabilization Ponds
WWTP	Wastewater Treatment Plant

ACKNOWLEDGMENTS

This report was written by Peter McCornick, Garry Grabow and Ramzi Sabella with the support of the support of Ramzi Sabella, Nisreen Haddadin and Bashaar Ammary.

Our colleagues in the Ministry of Water and Irrigation have been active partners in this work, and have exerted considerable efforts in contributing and validating the work. We would specifically like to acknowledge the valuable participation of Eng. Nazeer Abu Arqoob, Director Environment Directorate; Eng. Suzan Taha, Director MIS Directorate; Eng. Edward Qunqar, Director Water Resources Directorate; Eng. Rania Abdel Khaleq; Eng. Mohammed Mansour; and Eng. Yasser Nazzal.

In addition, the cooperation and enthusiasm of the staff of the Jordan Valley Authority (JVA), the Water Authority of Jordan (WAJ), the Royal Scientific Society (RSS), and the many others who worked with our team and greatly facilitated the work, has been invaluable.

Finally, the support of the United States Agency for International Development (USAID) Mission in Jordan, and the Associates in Rural Development (ARD, Inc.) team, in Jordan and Vermont, is highly appreciated.

EXECUTIVE SUMMARY

This document presents findings with respect to the Storage, Conveyance and Blending of reclaimed water in the Amman-Zarqa basin and Jordan Valley. Presented herein are details of the methodology used in characterizing the present and future features of storage, conveyance and blending of reclaimed water in the basin. Also, the document presents the results from the evaluation of several scenarios for future allocations of reclaimed water in the basin.

The primary tool used for this activity is an EXCEL based model (Reclaimed Water Allocation Model [RWAM-AZB]) that incorporates the various water quantity and quality characteristics of the Amman-Zarqa Basin, and the related parts of the Jordan Valley. Furthermore, those water quality constituents which do not lend themselves for inclusion in such a model or are not critical to intended uses, are addressed separately. In addition, other aspects related to the storage, conveyance and blending were examined.

The Reclaimed Water Allocation Model (RWAM-AZB) has been developed to balance the expected water supplies with the water reuse options (demands), and characterize the expected water quality in the Amman-Zarqa Basin and Jordan Valley. The model predicts water quality, and water supply status under various water supply and demand scenarios, and under different blending alternatives. The Reclaimed Water Allocation model is comprised of a flow component and water quality component. The water quality model uses information generated from the flow model.

The methodology, logic and governing equations used in the model for both the flow and the water quality are detailed in the Technical Reference in Appendix A. This technical reference includes the derivation of water supply and demand that are generated by or input to the model. Demand includes water requirements for agricultural and industrial use, as well as for groundwater recharge. The water quality modeling is divided into streamflow and reservoir modeling.

In addition to improving the reliability of water quantities being available at the time of demand, storage also plays a vital role in maximizing the benefits from blending. Presently there are two reservoirs that have a role in managing reclaimed water in the Amman-Zarqa basin. These are King Talal and Karameh reservoirs. Both are incorporated in the model. The King Talal Reservoir is a very important facility in managing the water supplies (baseflow, surface runoff and treated effluent) from the Amman-Zarqa basin to meet the demands of irrigation in the Jordan Valley, and improving the quality of the water reaching the Valley. The model allows for an additional in-stream reservoir in wadi Zarqa. It is placed downstream of KTR, where the most feasible sites appear to be located.

Allocation of Reclaimed Water

A range of scenarios for allocating expected reclaimed water resources were simulated. These preliminary analyses were used to consider the relative impact of options on each other. The final analysis will be conducted as part of developing the plan for managing water reuse in the basin, and the results will be presented in the final report. Generally, the highlands options, both for agriculture and industry, are relatively small. Their implementation will not have a significant impact on the allocation to the larger demands in the Karameh Directorate or the Northern Directorate. However, should allocations to either of these directorates have to be made before allocating reclaimed water to the highlands, the highlands options could not be implemented until well into the planning period (around year 2020). If both directorates were to be fully allocated, the highlands options could not be implemented until beyond the planning horizon (year 2025).

Water Quality

The TDS and Chloride levels reaching the Jordan Valley from the Amman-Zarqa basin are expected to trend slightly upwards due to the increasing influence of the reclaimed water. Also, the TDS levels of the outflow from the King Talal Reservoir (KTR) are expected to gradually increase relative to that of the inflow. Should, as expected, the quality of water supply to Amman improves (development of new sources from Zara-Main, Disi and KAC), the TDS and Chlorides will decline. However, without improved quality of supplies, the TDS and chloride levels reaching the Jordan Valley will gradually increase through the planning period (25 years).

The total phosphorous levels will continue to be reduced by residence time in the reservoir. In dry periods, where the reservoir is drawn down, the phosphorous levels reaching the Jordan Valley will remain high, although with no direct negative affect. However, the phosphorous levels in KTR will continue to cause algae blooms, which, will contribute to the total suspended solid levels reaching the valley.

The Total Nitrogen levels discharging from As Samra will be reduced and, as is the case now, the Ammonium will decrease and Nitrates increase along the wadi length. A modest further decline in Ammonium levels will occur in KTR. Oxidation will lead to declines in ammonium (although most is done in the wadi), while denitrifying (reducing) type conditions will transform nitrate to nitrogen gas, except during periods where the reservoir is drawn down.

With the implementation of the new facilities at As Samra, the fecal coliform levels in the effluent are expected to comply with the Jordanian Standards (MPN 1000). However, the contamination from other sources will maintain higher fecal coliform levels in the wadi. The reservoir will continue to play an important role in significantly reducing the FCC levels. When the reservoir is drawn down, residence time is reduced, and therefore FC levels are not dramatically decreased.

Due to the presence of KTR and it's sediment trapping function, TSS levels at the reservoir outlet are, and are expected to remain, generally low. However, as with other constituents, the TSS rises when the residence time in the reservoir is short. Also, although not related to reclaimed water, the TSS rises between the outlet and the diversion point. In conclusion, TSS will remain an issue at the field level, which will need to be addressed by filtration systems and their management.

Storage

Additional storage facilities that could be utilized for managing reclaimed water in the Amman-Zarqa basin include the existing Karameh dam, a potential site for an in-stream dam downstream of the existing King Talal reservoir (KTR), and artificial groundwater recharge in the Jordan Valley. Increasing surface storage by around 20 MCM, either by using Karameh dam or a new facility, will allow the scenarios to be implemented more aggressively. Further increases in surface storage have little effect and, with time, the increasing reliability due to increasing volumes of reclaimed water, means that existing storage will be more effective.

Large-scale dredging to remove the sediment from King Talal Reservoir does not appear advisable, unless the cost of developing further storage in the future is very expensive. The levels of trace elements and heavy metals in the sediment do not present a major risk, and keeping these in-situ in the reservoir is the best course of action.

At this time, the Karameh reservoir is not intended for storing reclaimed water. Furthermore, the elevation of salt levels due to saline springs, the local soils and evapo-concentration, limited the viability of water stored in this reservoir. From the information available, further experience is required with the operation of the reservoir under non-drought conditions, to determine the expected quality of the water.

Artificial recharge of groundwater may present an opportunity to improve, in terms of quantity and quality, shallow groundwater supplies available in parts of the Karameh and Middle Directorates. These resources could be accessed during dry periods when surface water supplies are low. However, the need for such storage will become less important as the reliability of the surface water supplies improve.

Conveyance

Enhancement and expansion of the conveyance facilities was examined with regards to supply reclaimed water to the various options investigated, and in managing reclaimed water in the basin. The details for each option are presented in the relevant options report. Unless the reclaimed water is to be used for non-agricultural purposes (industry) or to be exchanged with existing uses of freshwater, the pumping and conveyance costs must be kept to a minimum for any such development to be economically viable.

The proposals to develop major pipelines to carry the reclaimed water from the wastewater treatment plants, down the wadi and past the reservoir, are, because of the volumes involved, very costly. In addition, the benefits, either by reducing the impact on water quality in the reservoir or preventing use of the reclaimed water in Wadi Zarqa, are unlikely to be achieved.

Blending

In addition to the blending of reclaimed water with runoff and baseflow in Wadi Zarqa, the real-time and seasonal blending in the Jordan Valley are important components of water quality management in the Jordan Valley. In recent years, the quantity of freshwater available for blending has been very limited. As reclaimed water becomes more dominant in the basin, the relative portion of freshwater is set to decline. As it is Government Policy not to allocate further freshwater to irrigation, the quantity and timing of freshwater supplies are likely to remain the same, with excess flows in the wetter periods allocated to the areas receiving reclaimed water.

I. INTRODUCTION

This document presents the detailed investigations of the storage, conveyance and blending of reclaimed water in the Amman-Zarqa Basin and Jordan Valley, including the methodology used to investigate the potential scenarios for allocating reclaimed water in the basin, and the results obtained. In considering a scenario, not only must present and future supplies of reclaimed and natural water supplies be balanced with present and future demands, but the expected quality of the supply at a given reuse site must also be accounted for.

This document begins with an overview of the situation and the general approach, or methodology, adopted to investigate the basin level management requirements; including storage, conveyance and blending, for a selected scenario. The Reclaimed Water Allocation Model for the Amman-Zarqa Basin (RWAM-AZB), developed to facilitate the analysis of scenarios for allocating the reclaimed water and the subsequent impact on water quality, is described and the general analysis of scenarios presented. In addition, other relevant aspects of basin-level management for water reuse not considered in the model, are examined. The final scenario for allocating reclaimed water in the basin will be presented in plan (MWI/ARD, 2001j).

I.1. BACKGROUND

As the quantity of effluent discharged to wadi Zarqa increases (MWI/ARD, 2001d), the careful management of these reclaimed water and the available fresh water for blending, is essential to maximize the use of this valuable resource. The management components for controlling this supply to meet the demands are the storage, conveyance and blending.

Under each scenario being considered, utility of existing storage facilities and the need for new facilities, in terms of timing and volume, need to be established. In addition to improving the reliability of the water supply, storage also plays a vital role in maximizing the benefits from blending.

At present, the conveyance of the reclaimed water has been via the natural wadi, through King Talal Reservoir and on to the Jordan Valley. Under future scenarios, the development of additional conveyance facilities may be required to make maximum use of the reclaimed water.

The main quality concerns, at least with regards to the economic viability of irrigated agriculture, are total salts and chlorides (Grattan, 2000). These are not easily removed, but their effect can be offset through dilution or leaching. The limited fresh water available for either dilution or leaching must be used as efficiently as possible.

I.2. OBJECTIVES

The overall goal with this activity is to examine the basin-level tools; that is the storage, conveyance and blending; required for managing reclaimed water under various scenarios.

I.3. SCOPE & LIMITATIONS

These investigations are concerned with determining the allocation of reclaimed water in the Amman-Zarqa basin and Jordan Valley through 2025. Because of the importance of other water sources in the successful use of reclaimed water, the present and future characteristics of these have to be also considered.

The primary tool developed to facilitate these investigations is an EXCEL-based model (RWAM-AZB), which accounts for the relevant characteristics of the basin, including the present and future flows, and the key water quality constituents. The model allows the demands of a selected scenario to be balanced with the expected water supplies, and to examine the potential impacts on key water quality constituents. The model allows investigation of the impact of changes in the storage and conveyance system, including new storage, and variations in the supply of water. Not all quality constituents either lend themselves or need to be included in such a model, and, where relevant, are addressed separately in this document.

II. OVERVIEW & GENERAL APPROACH

This chapter provides an overview of the setting for storage, conveyance and blending in the Amman-Zarqa basin, and describes the basic approach taken in analyzing the situation and investigating the impact of various management scenarios.

II.1. OVERVIEW

Many aspects of water quantity and water quality in the Amman-Zarqa basin have been studied in the past, with the most comprehensive and definitive being that related to the wastewater masterplan (Harza, 1997), and the most recent being the efforts conducted concurrent to these investigations as part of the National Water Management Plan (JICA, 2000).

II.2. GENERAL APPROACH

This sub-chapter discusses the basic approach taken in developing an understanding of the basin level water control (storage, conveyance and blending) requirements for the various scenarios that will be considered as part of the plan. The detailed methodology for investigating major water management components of the basin is presented elsewhere in this document.

The primary tool for this activity is the EXCEL based model (RWAM-AZB) that incorporates the various water quantity and quality characteristics of the Amman-Zarqa Basin, and the related parts of the Jordan Valley. This has been developed over the course of the water reuse planning exercise. Details are provided in Appendix A

In addition, a number of the issues to be considered under this activity cannot be addressed by the model and, therefore, are addressed separately.

II.2.1. Water Quality

Water quality was investigated, and characterized in terms of its intended use, which, in the case of the Amman-Zarqa Basin, is agriculture and, to a lesser extent, industry.

<u>Agriculture</u>

The constituents in the reclaimed water of most concern to agriculture are total salts and chloride. The sodium adsorption ratio is of no hazard, especially when considering the salinity of the reclaimed water (FAO, 1995; Grattan, 2000). Boron, which is of concern to sensitive crops such as citrus, is of interest (FAO, 1985).

Other water quality parameters of interest to agriculture are nutrients. Nitrogen and phosphorus are the primary nutrients available in the reclaimed water. While excessive nutrients are normally considered to be pollution in streams and reservoirs, they may be used to reduce the applied fertilizer requirement when used for irrigation. For each mg/l of nitrogen in reclaimed water, 1 kg/ha of nitrogen is applied with 1 meter of irrigation. Excessive nutrients, can however, promote excessive vegetative growth and not additional fruit yield (Grattan, 2000).

Nutrients modeled are total nitrogen, nitrate nitrogen and total phosphorus. As the reclaimed water moves downstream from its source, ammonium oxidizes to nitrite and nitrate. This exerts what is called a "nitrogenous oxygen demand" on the river, and along with biological oxygen demand (BOD) reduces dissolve oxygen in the waters downstream of the plant. As the average pH of As Samra effluent is 7.9, most ammonia is in the form of ammonium and therefore little loss through volatilization occurs. The process of converting organic nitrogen to ammonia is much slower. Nitrate-nitrogen is the form most readily available to plants.

Total Phosphorus is comprised of dissolved phosphorus (normally phosphate) and insoluble forms that are normally bound to sediment. The total phosphorous rate constants developed for use in the model are indicative of sediment settling, which reduces the phosphorous load downstream.

Due to general health effects and possible contact with field workers, fecal coliform was also selected for modeling.

<u>Industry</u>

Although specific quality needs vary from industry to industry, in general water quality parameters of concern for industrial uses are typically, total solids, ph, and alkalinity. Solids are a concern due to clogging and contribution to biological growth, while ph and alkalinity are indicative of the likelihood of corrosion or deposition in pipes and tanks. Pathogens may be of concern if they are transmitted as aerosols via cooling water vapor.

Reclaimed water for industrial reuse will be piped directly from As Samra, and not conveyed in the wadi. It is anticipated that upgrades in the As Samra treatment plant will produce effluent suitable for industrial uses. Some pretreatment, such as ph adjustment may be required. Struvite (magnesium ammonium phosphate) formation may also be a concern. Struvite precipitation problems are normally dealt with by using precipitation inhibitors. Details on the water quality requirements for industry are presented in the component working paper on water reuse by industries (MWI, 2001h).

<u>Metals</u>

None of the metals present in As Samra effluent or to some extent present in Zarqa runoff are in concentrations sufficient to affect crop yield (Grattan, 2000). Much of the metals are settled in KTR and adsorbed to the bottom sediments. It is probably best to let the toxic metals bury themselves in the sediment rather than to try dredging operations. Dredging would re-suspend sediments containing the heavy metals and allow them to be transported downstream.

BOD, COD

BOD and COD are typical measurements of wastewater treatment plant performance, but are not of primary concern for agricultural use. The Jordanian standard for release into Wadis is 50 mg/l. An oxygen sag curve persists downstream of the outfall until natural re-aeration processes bring dissolved oxygen levels to normal.

TSS

Total suspended solids (TSS) can present a problem for irrigated agriculture, especially for drip irrigation, in the form of physical clogging. Suspended solids should be analyzed to determine their composition between inorganic and organic material. Physical clogging problems can also be exacerbated by bacteria. While bacteria indicates a potential biological clogging problem, certain bacteria may also produce iron and manganese oxides also known as iron ochre, which is a combination of the iron oxide precipitate and filamentous algae.

In the case of the Amman-Zarqa basin, there is not enough data at higher flows to develop a sediment concentration versus discharge relationship, therefore, it was not included in the modeling exercise, but addressed as part of the review of scenarios.

III. RECLAIMED WATER ALLOCATION MODEL (RWAM-AZB)

The Reclaimed Water Allocation model was developed to predict water supply and water quality for various water reuse management scenarios in the Amman-Zarqa Basin and Jordan Valley. The model predicts water quality, and water supply status under various water supply and demand scenarios, and under different blending alternatives. The Reclaimed Water Allocation model is comprised of a flow component and water quality component. The water quality model uses information generated from the flow model.

III.1. TECHNICAL DETAILS

The methodology, logic and governing equations used in the model for both the flow and the water quality are detailed in the Technical Reference in Appendix A. This technical reference includes the derivation of water supply and demand, the synthesis of flow, and estimated agricultural and industrial demands used in setting up the model. Modeling of lake evaporation is also explained.

The water quality modeling is divided into streamflow and reservoir modeling. Further differentiation is given between reactive or decaying water quality variables, and conservative variables. For streamflow modeling, derivation of first order rate constants is explained and k values are given. Rate constants based upon mass balance principles are derived for reservoir modeling.

Water quality modeling limitations

Water quality as predicted in the model is based upon rate equations that empirically fit measured water quality data and its transformation over time and distance in a river or transformation within a reservoir. These rate constants include the effect of non-point sources that contribute to contamination and nutrient enrichment to Wadi Zarqa. If additional point sources develop in the future (or conversely if sources diminish) then the model will not in all probability be as accurate. Predicting the impact of additional sources or fewer sources would be difficult and could best be achieved within the model by adjusting the rate constants. If substantial basin changes are anticipated, a better prediction could be achieved by a thorough basin inventory and the use of a non-point source water quality such as AGNPS (USDA, 1998) or BASINS (USEPA, 2000).

III.2. MODEL OPERATION

This model was not intended for use beyond the life of the water reuse planning exercise. However, to ensure that it could be operated with limited supervision of the specialist consultant, a basic users manual was developed (see Appendix B) and local team members trained in its operation.

IV. ANALYSIS OF SCENARIOS – APPLICATION OF THE MODEL

This chapter presents the analysis of scenarios, where scenarios are various configurations of options, for allocating reclaimed water in the Amman-Zarqa Basin and Jordan Valley. This is the application of the allocation model, present elsewhere in this document.

The scenarios, and therefore the results, presented here are not final, as the final scenario for managing the basin will require further feedback from stakeholders. The final results will be presented as part of the plan, using the assumptions, approach and methods described herein.

This chapter is divided into four sub-chapters, which are, a general overview of the scenarios, allocation of reclaimed water for a range of scenarios, impact on water quality, and an analysis of the sensitivity of the allocations to increasing storage and variations in the supply of water.

IV.1. OVERVIEW OF SCENARIOS

At the time of writing, the prioritization of options was evolving and some of the options reports were yet to be completed. This analysis of scenarios was iterative as new information developed.

The first iteration considered a broad range of preliminary, or basic, scenarios that allowed the model and general methodology to be tested, and provide an overview of the likely extremes for managing the basin. Subsequent scenarios were developed from a screening of options based on the identified planning objectives (replacing fresh water supplies and maximizing economic returns).

IV.1.1. Summary of Options

The options for using reclaimed water have been identified and characterized as part of the planning process, and are presented in the relevant options reports. These reports are:

- Water Reuse in **Wadi Zarqa** & from **Other Amman-Zarqa Sources** (MWI/ARD, 2001b)
- Water Reuse Options in the **Jordan Valley** (MWI/ARD, 2001e)
- Options for **Artificial Groundwater Recharge** with Reclaimed Water in the Amman-Zarqa Highlands and Jordan Valley (MWI/ARD, 2001g)
- Water Reuse Options for **Industrial and Municipal Purposes** in the Hashemite-Zarqa-Rusefeih (HZR) Area (MWI/ARD, 2001h)
- Pre-Feasibility Study – Water Reuse for **Agriculture and/or Forestry in the Amman-Zarqa Highlands** (MWI/ARD, 2000b)

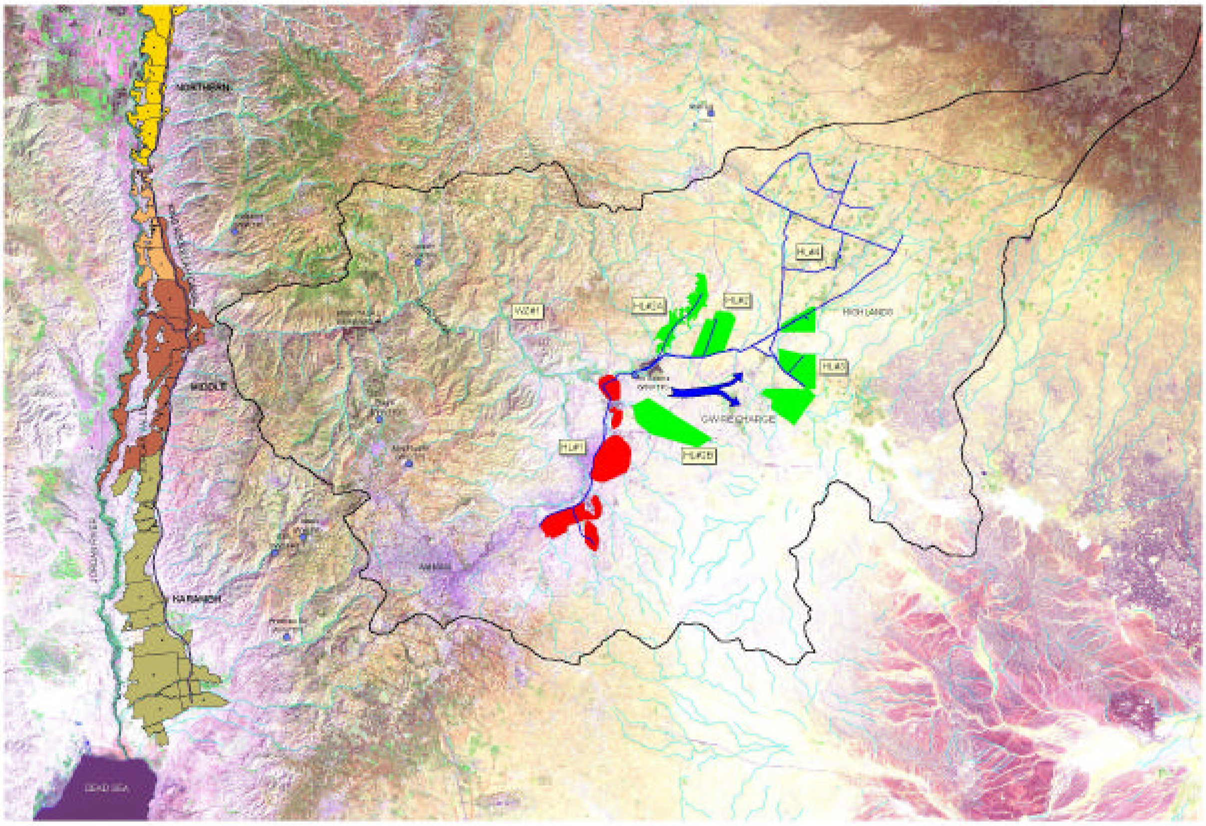

Figure IV.1. Locations of options investigated as part of the water reuse planning process

IV.1.2. Preliminary Scenarios (Scenario Groups A & B)

The model was first tested on a wide range of scenarios (scenario group A and B) based on a comprehensive list of possible options, as listed below. Further details on these initial scenarios are provided in Appendix D. These scenarios were developed to consider extremes of option configurations and re-sequencing of the same. These initial scenario investigations allowed insights into water management in the basin, general testing of the model and identification of required improvements and modifications to the model.

The list of options considered were:

1) Hashemite-Zarqa-Ruseifeh (HZR) Industrial/Municipal Water Reuse
2) Groundwater Recharge in the Highlands
3) Wadi Dhuleil Irrigation Project (HL#3)
4) Minor Wastewater Treatment Plant Options
5) Groundwater Recharge in the Jordan Valley
6) Wadi Zarqa Intensification

7) Middle Directorate Intensification
8) Karameh Directorate Intensification
9) Northern Directorate Replacement

IV.1.3. Working Scenarios (Scenario Group C)

Following the preliminary analysis, the more realistic scenarios were identified. A general characterization of the options, drawn from the relevant options reports, is presented in Table IV.1. The table includes an initial assessment of each option's ability to meet existing or future demands on fresh water, and to maximize economic returns.

It is assumed that the present users of reclaimed water have "prior right" to the resource, and, future allocations will be from the expected increases in supply of reclaimed water. These present users are farms in Wadi Zarqa, the Middle Directorate, the Karameh Directorate and, although yet to be implemented, the Hashemite University. Furthermore, given that farmers in Wadi Zarqa view the presently fallow lands as historically irrigated, it will require limited investments to bring back into production, and that it will be difficult to prevent such development from occurring, it is prudent to assume in all scenarios this "option" will occur in the short to medium term.

Although there is a possibility that new fresh water sources may become available for irrigated agriculture in the Jordan Valley, this is not likely, especially considering the chronic National water deficit and the Government's policy to exchange effluent for fresh water resources. It is assumed that, as a best-case, fresh water resources available for agriculture will remain as they are now.

Table IV.1. Summary of results from preliminary options review

Description and location of option	Estimated additional demand	Type of option	Freshwater savings	Net economic benefits	Advantages	Disadvantages
Fulfilling existing reclaimed water needs/commitments for intensification of irrigated agriculture in the Middle Directorate	6 MCM	JV[1] irrigation	0	Medium	Low cost	Minimal
Fulfilling existing recycled water needs/commitments at Hashemite University	1.5 MCM	HL[2] irrigation				
Expansion/intensification of irrigation to all the irrigable area of Wadi Zarqa	3 MCM	Wadi Zarqa	0	Medium	Low cost	Expanded misuse of high FCC water.
Local irrigation and/or groundwater recharge of effluent from the minor wastewater treatment plants	7 MCM	Minor WWTPs	Exchange with existing irrigation	Medium	Low to medium delivery & conveyance costs.	Further treatment requirements.
Industrial and Municipal supply in the Hashemite-Zarqa-Rusefieh (HRZ) area	20 MCM	HL industry	Yes. + 7 MCM.	Medium to high.	Ability of user to pay. Close to source.	High treatment requirements.
Supply to a potential new irrigation site approximately 5-km northeast of As Samra	11 MCM	HL irrigation HL#2	0	Low.	Less expensive than HL#3 or HL#4.	Land resources not sustainable under irrigation. High conveyance and delivery costs.
Supply to a potential new	12 MCM	HL irrigation	0	Low	Less expensive than	Conveyance and

[1] JV – Jordan Valley
[2] HL - Highlands

irrigation site approximately 5-km North of As Samra		HL#2a			HL#2, and better land.	delivery costs still high.
Supply to a potential new irrigation site located approximately 5-km East As Samra	~ 8 MCM	HL irrigation HL#2b	0	Low	Less expensive than HL2a. Least expensive of all highlands agriculture options.	Less irrigable land than HL#2a. Conveyance and delivery costs still high.
Supply to Wadi Dhuleil irrigation project located approximately 14km East of As Samra	9-15 MCM	HL irrigation HL#3	2.5 MCM	Low	Provides new water source to existing irrigation project.	Conveyance and delivery costs are higher than HL#2, 2a & 2b. "Fresh" water for exchange is saline.
Supply to Wadi Dhuleil irrigation project and individual farms in area, and extending to Hallabat.	9 MCM	HL irrigation HL#3a	9 MCM	Low to Medium	Provides new water source to existing irrigation project and farms.	Conveyance & delivery costs higher than HL#2, 2a & 2b. Network to farms will be expensive.
Farms in the Highlands currently irrigating from the Basalt/B2/A7 Aquifer, llocated approximately 40km North-East of As Samra	20 MCM	HL irrigation HL#4	20 MCM	Low	Large volume of fresh water exchanged.	Conveyance & delivery costs are very high.
Intensification of irrigated agriculture in Karameh Directorate of the Jordan Valley	40 MCM	JV irrigation	0	Medium	Area already developed for irrigation.	
Supply to irrigated agriculture in the Northern Directorate of the Jordan Valley	58 MCM	JV irrigation	58	Medium to high, if replacement of fresh water is benefit.	Potential to meet short-fall in water supplies if freshwater transferred to Amman.	Conveyance pipeline is expensive. Large volume of demand.
Groundwater recharge in the Highlands	ND	HL recharge		Medium	Direct replenishment of groundwater.	Potential areas are underlain by important aquifers. Geology is not ideal.
Groundwater recharge in the Jordan Valley	ND	JV recharge		Low	Storage for long-term carry-over. Relatively low cost.	Potential impact on existing GW.

From the above, the basic prioritization was based on first meeting the existing demands, and then a considering either replacement of freshwater or economic returns. When the overall economic analysis is completed, and if an opportunity cost is placed on fresh water, the economics can be used to prioritize all options.

The pre-existing additional demands for reclaimed water are:

- Intensification of the Middle Directorate,
- Intensification of Wadi Zarqa, and
- Hashemite University.

From potential savings in freshwater, the options of interest are:

- HZR Industrial & Municipal project (HL#1);
- Minor WWTP;
- Dhuleil and area irrigation project (HL#3a); and
- Northern Directorate (only in the event freshwater supplies are transferred).

With respect to economic returns from the resource, the prioritization of options are as follows:

- Karameh Directorate Intensification;
- HZR Industrial & Municipal project (HL#1);
- Minor WWTP;
- Northern Directorate (only in the event freshwater supplies are transferred), and
- Dhuleil and area irrigation project (HL#3a).

The expected and existing reclaimed water requirements for each of the key options were developed in the options report, and are summarized in Table IV.2.

Table IV.2. Summary of existing and potential requirements for reclaimed water in the Amman-Zarqa Basin & Jordan Valley

	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EXISTING[2]													
Wadi Zarqa	18,822,876	821,100	821,100	821,100	1,586,304	2,379,456	2,511,648	2,423,520	2,467,584	2,026,944	1,321,920	821,100	821,100
- recycled water only	9,411,438	410,550	410,550	410,550	793,152	1,189,728	1,255,824	1,211,760	1,233,792	1,013,472	660,960	410,550	410,550
Middle Directorate[1]	45,802,499	2,475,691	2,475,691	2,649,812	5,663,269	4,993,477	3,935,043	3,342,284	5,373,082	5,421,777	4,520,989	2,475,691	2,475,691
- recycled water only	36,641,999	1,980,553	1,980,553	2,119,850	4,530,615	3,994,781	3,148,034	2,673,827	4,298,466	4,337,421	3,616,791	1,980,553	1,980,553
Kharameh Directorate[1]	36,549,661	2,183,870	2,183,870	2,113,627	4,517,317	3,983,056	3,138,794	2,665,979	4,285,848	4,324,690	3,606,175	1,362,565	2,183,870
- recycled water only	29,239,729	1,747,096	1,747,096	1,690,902	3,613,853	3,186,444	2,511,035	2,132,783	3,428,679	3,459,752	2,884,940	1,090,052	1,747,096
Minor WWTP (Jerash)	600,000	26,179	26,179	26,179	50,575	75,863	80,077	77,268	78,672	64,624	42,146	26,179	26,179
FUTURE ADDITIONAL WATER REQUIREMENTS FOR RECYCLED WATER[2]													
Wadi Dhuleil Irrigation Project (HL#3)	8,729,600	460,000	460,000	460,000	762,100	1,000,400	1,101,500	993,400	1,039,700	894,600	637,900	460,000	460,000
HZR - Industrial/Municipal Water Reuse[3]	20,000,000	1,666,667	1,666,667	1,666,667	1,666,667	1,666,667	1,666,667	1,666,667	1,666,667	1,666,667	1,666,667	1,666,667	1,666,667
Irrigated Agriculture in Wadi Zarqa	3,321,684	144,900	144,900	144,900	279,936	419,904	443,232	427,680	435,456	357,696	233,280	144,900	144,900
Middle Directorate Intensification	6,000,000	324,309	324,309	347,118	741,873	654,132	515,480	437,830	703,859	710,238	592,237	324,309	324,309
Kharameh Directorate Intensification	39,600,000	2,366,130	2,366,130	2,290,025	4,894,320	4,315,471	3,400,750	2,888,475	4,643,534	4,685,617	3,907,137	1,476,281	2,366,130
Northern Directorate Replacement[1]	56,970,430	2,800,000	2,800,000	2,977,929	7,071,381	6,478,107	5,229,240	4,470,223	7,131,468	6,980,064	5,432,019	2,800,000	2,800,000
Minor Wastewater Treatment Plant Options	6,600,000	287,916	287,916	287,916	556,233	834,349	880,702	849,800	865,251	710,742	463,527	287,916	287,916

[1] *Mixture of recycled and other water sources*

[2] *Assumes sufficient water supply to fully meet demand*

Indicates water supply is mixture of recycled and other sources. Estimated recycled volume is presented in row below

Following the preliminary analysis of the broad range of potential scenarios and the screening process presented above, the scenarios were condensed to:

C.1. Hashemite-Zarqa-Rusefieh (Industrial & Municipal); Dhuleil Irrigation Project & area farms; Minor WW Treatment Plants; Karameh Directorate.
C.2. Karameh Directorate; Hashemite-Zarqa-Rusefieh (Industrial & Municipal); Dhuleil Irrigation Project & area farms; and Minor WW Treatment Plants.
C.3. Northern Directorate; Hashemite-Zarqa-Rusefieh (Industrial & Municipal); Dhuleil Irrigation Project & area farms; Minor WW Treatment Plants; Karameh Directorate.
C.4. Karameh Directorate; Northern Directorate; Hashemite-Zarqa-Rusefieh (Industrial & Municipal); Dhuleil Irrigation Project & area farms; and Minor WW Treatment Plants.

IV.2. ALLOCATION OF RECLAIMED WATER

The analysis of scenarios was divided into balancing the supplies and demands in the basin (water quantity) and, having achieved a balance for the basin, assessing the impact on water quality at key points in the basin (see section IV.3. below).

The RWAM spreadsheets were used to allocate the reclaimed water. Initial conditions were set as the reclaimed water supplies (quantity and quality) as developed in MWI/ARD (2001d), a conservative estimate of the natural hydrology of the basin (65 percent of the long-term average), and demands as determined in the options reports, and summarized below. Further preliminary assumptions were no additional storage and gradual silting up of King Talal Reservoir. The objective in analyzing each scenario is to determine the most aggressive schedule (start date for each option) without the annual deficit exceeding 5 percent in any of the 25 years of the planning period.

In addition to the conservative hydrology, the basic assumptions were:

- Sedimentation occurs in KTR at an average annual rate of 0.65 Mm^3 (Harza, 1996);
- Since flow data are limited for station 200 (the wadi which discharges directly into KTR) was correlated with flow in wadi Zarqa (station 0060);
- Reach losses were assumed to be 10%;
- Additional storage set to zero;
- KTR has an initial capacity at the beginning of the simulation period of 15 M-m^3 and a total live capacity of 75 M-m^3 ; and
- Blending ratio at the mixing point at KAC is 20 percent fresh water.

The results for each of the above scenarios are included in Appendix E. As an example, the results from the analysis of scenario C(2) are shown in Figure IV.2.

For the scenarios discussed above, the schedules for fully meeting the demands of each of the options are as follows:

C(1) HZR (2006); Dhuleil (2008); MWWTP (2012); and Karameh (2020).
C(2) Karameh (2010); HZR (2018); Dhuleil (2019); and MWWTP (2020).
C(3) Northern (2010); HZR (2026); Dhuleil (2027); MWWTP (2028); and Karameh (>2030).
C(4) Karameh (2010); Northern (2018); HZR (>2030); Dhuleil (>2030); and MWWTP (>2030).

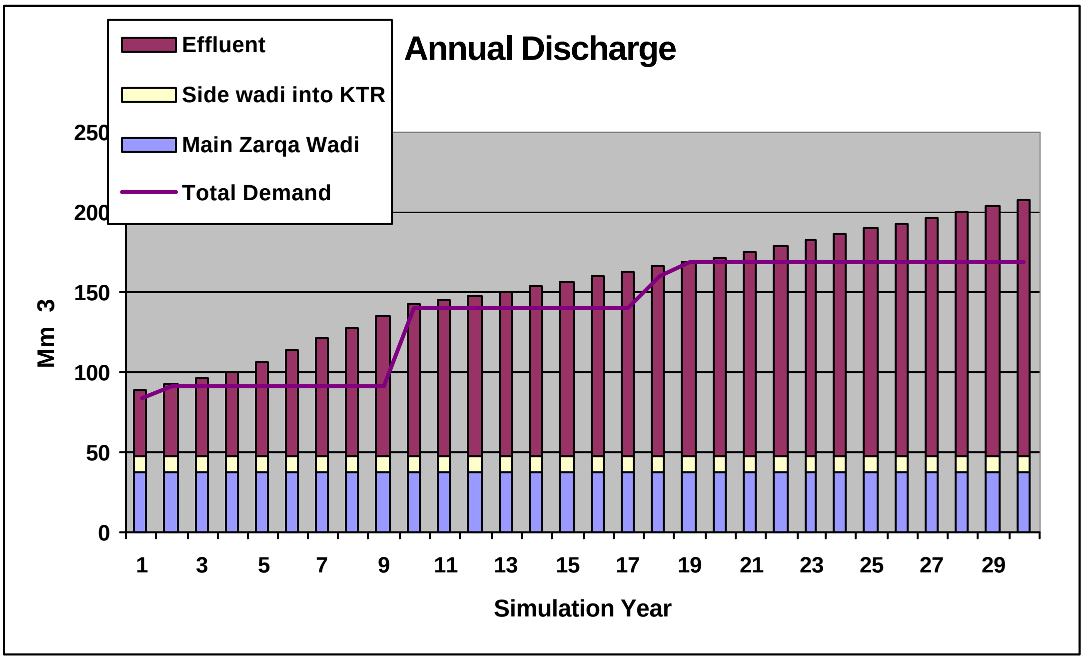

Figure IV.2. Surface supplies (reclaimed & natural) and demands for scenario C2.

From the example scenario (C1) above, to supply the options in the highlands before meeting the needs of the Karameh Directorate, will delay the full allocation of water supply to this Directorate until 2020. However, should the needs of this Directorate be given priority (scenario C2), this will delay the fully implementation of the highlands options, with the full needs of the HZR only being met in 2018. The delay in implementing the highlands options will be even greater if the needs of the Northern Directorate have to be fully met first. Finally, if all of the Jordan Valley was to be supplied with reclaimed water from the Amman-Zarqa basin, none of the highlands options could be reliably supplied until well past the planning timeframe (2025).

IV.3. IMPACT ON WATER QUALITY

As discussed in Chapter II, the water quality constituents of primary interest with respect to water reuse in the Amman-Zarqa basin are those which would impact agriculture or, to a lesser extent, industry. In the case of irrigated agriculture in the Amman-Zarqa basin and the Jordan Valley, these are total salts and chloride. In addition, at certain times of the season, excess nutrients, in the form of nitrogen and phosphorous, can promote excessive vegetative growth rather than additional fruit yield (Grattan, 2000). Furthermore, microbiological contamination, expressed in terms of fecal coliform count (FCC), is of concern. All of these constituents are included in the modeling exercise. Detailed outputs from the model for the above scenarios are presented in Appendix G.

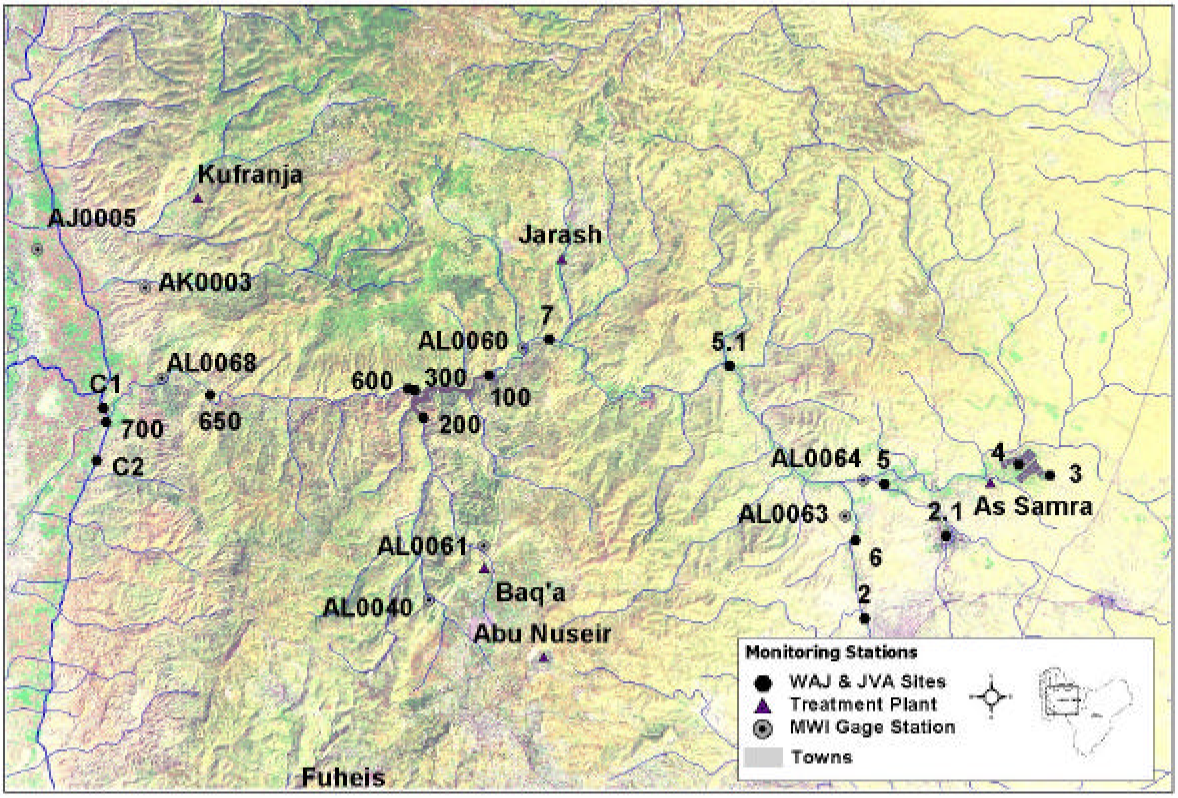

Figure IV.3. Water quality monitoring and gaging stations in the Amman-Zarqa basin and Jordan Valley

The results from the water quality model portion of the RWAM-AZB are meant to show trends and relative changes as various scenarios are implemented. Natural variability in the physical system, as well as model uncertainty, mean that values generated by the model should be treated as a "best estimates" and not considered as "100% accurate". The results reporting on here assume that the quality of the effluent produced from As Samra will be as predicted from the new facilities.

This section presents the water quality results obtained from the model, using one scenario [C(2)] as an example. Results from other scenarios are presented in Appendix G. However, the results from the analyses of these and other scenarios demonstrate that the major factor in influencing the quality parameters, once the new As Samra facilities have been developed, is the retention time in the reservoir. Scenarios which include further options, or demands, in the Jordan Valley, thereby drawing down the reservoir, have a negative impact on certain water quality constituents.

IV.3.1. TDS & Chlorides

All scenarios examined using the model show, as expected, maximum TDS and chloride levels trending slightly upwards over the course of the planning period (25 years) due to the increasing influence of reclaimed water. The results from scenario C(1) are shown in Figures IV.3. and IV.4. Seasonal variability of salt and chloride should decrease over time due to increased reclaimed water discharge. However, the KTR inlet and outlet levels for both TDS and Chlorides gradually diverge over the planning period as reclaimed water becomes more dominant. It is important to note that the upward trend in maximum TDS does not consider the likely lower TDS levels in the water supplies that are to be developed for Amman in the near to medium term (Zara-Main, Disi, and KAC).

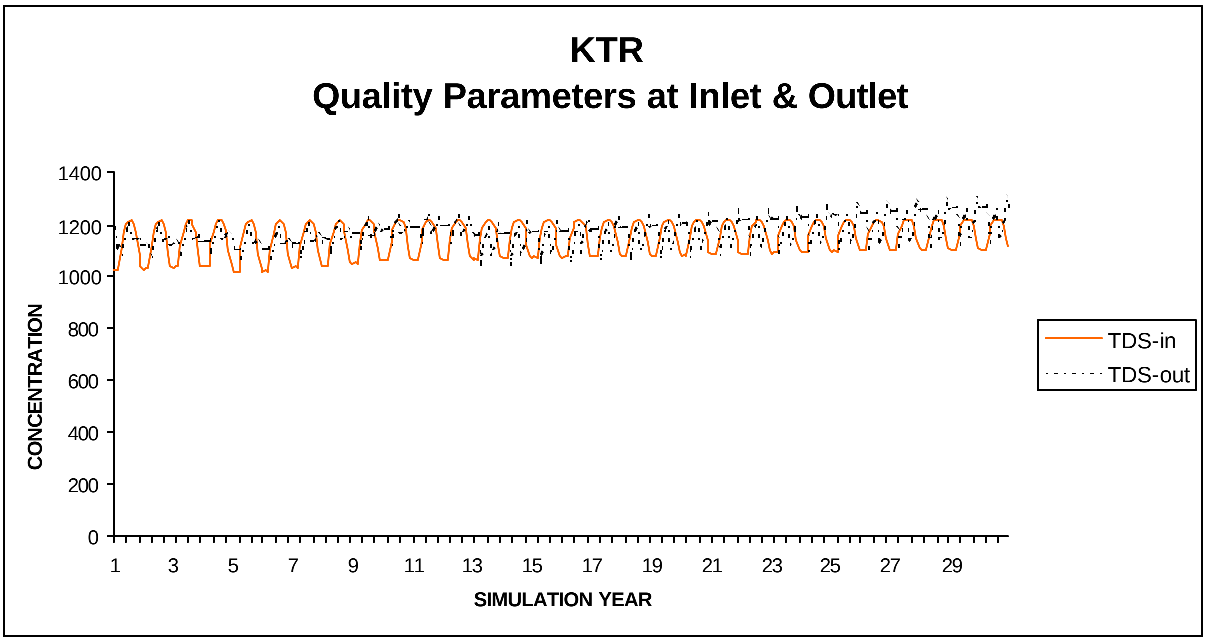

Figure IV.3. Projected TDS concentration in KTR inflow and outflow (Scenario C(1))

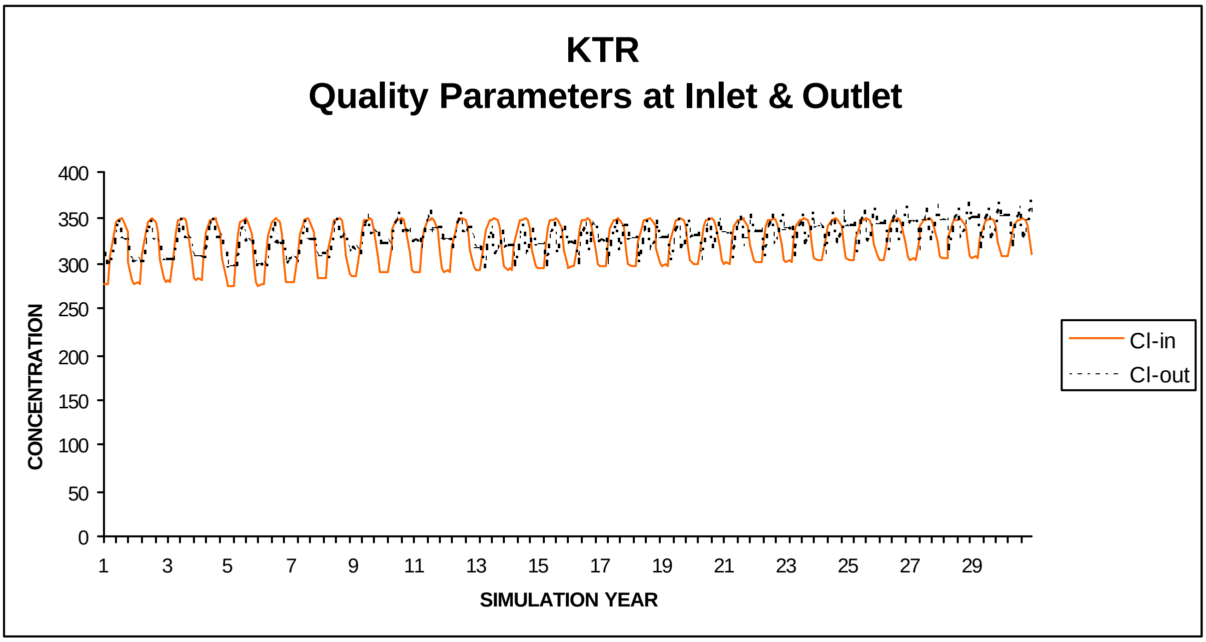

Figure IV.4. Projected Chloride concentration in KTR inflow and outflow (Scenario C(1))

IV.3.2. Total Phosphorus

Total Phosphorus concentration in the outflow from KTR and from any proposed reservoir is expected to decrease as compared to inflow concentrations. This is primarily due to soil adsorbed phosphorus and sedimentation within the reservoir. Additionally, some uptake of dissolved phosphorus is expected from algae or aquatic vegetation. Total phosphorus reduction is decreased by lower reservoir levels and thus shorter detention times. As shown in Figure IV.5., the model demonstrates the total phosphorous concentration lower than the inflow, except when (simulation years 15 to 23) the reservoir levels are drawn down, as shown in Figures IV.6., and IV.7.

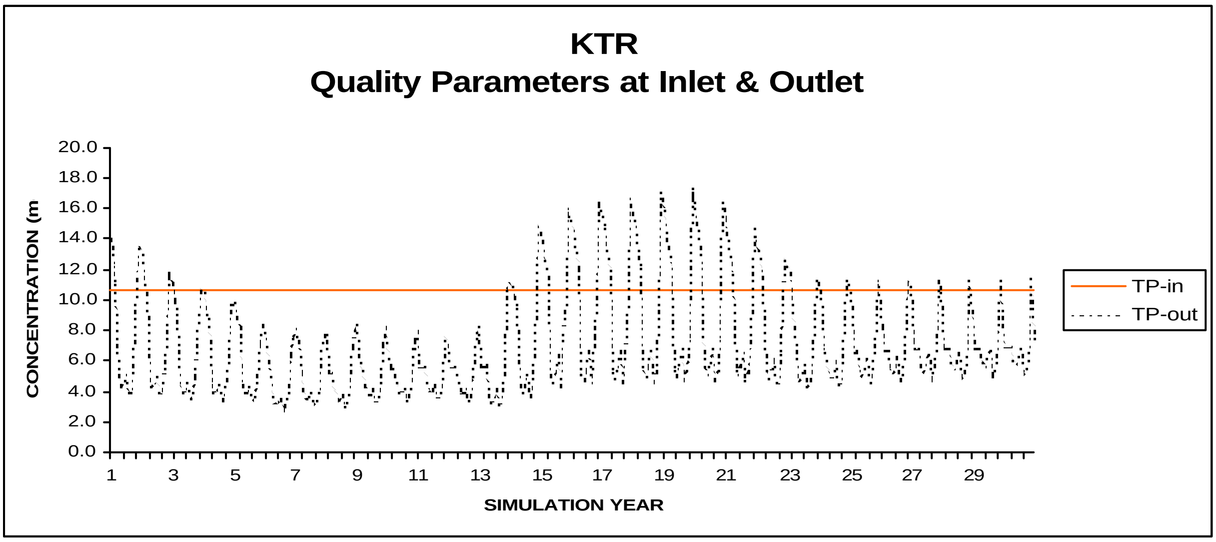

Figure IV.5. Projected total phosphorus concentration in KTR inflow and outflow (scenario C(1))

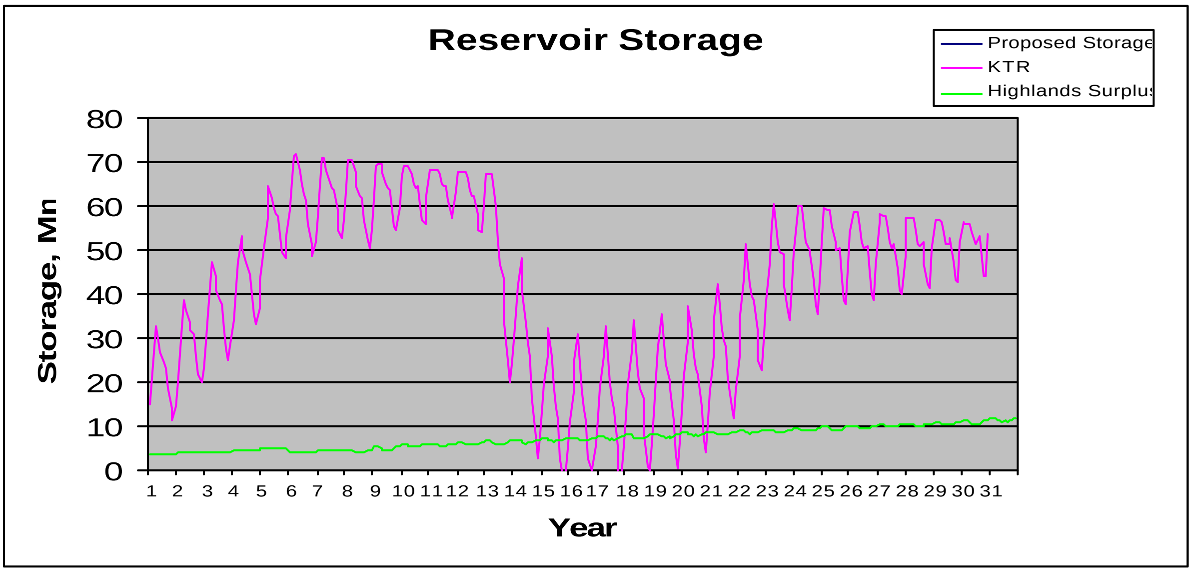

Figure IV.6. Projected KTR storage levels (scenario C(1))

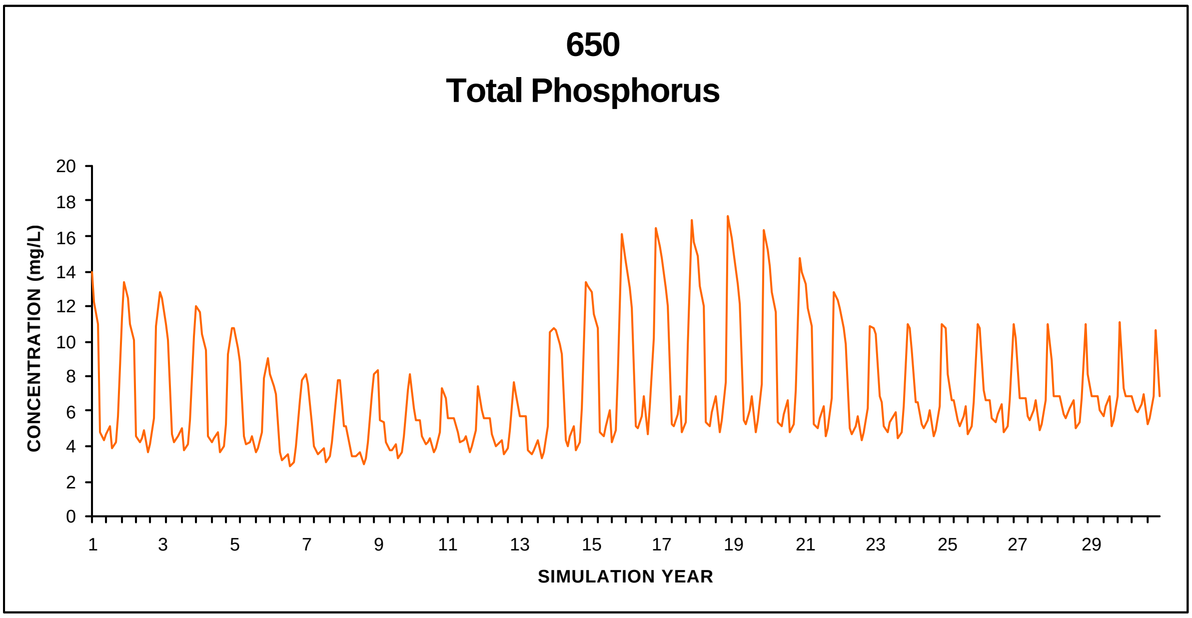

Figure IV.7. Projected Total Phosphorus concentration at station 650 (scenario C(1))

IV.3.3. Ammonium & Nitrate

Ammonium is expected to decrease in a downstream fashion as it has historically due to oxidation to nitrite and nitrate. By the same reasoning, nitrate is expected to increase in a downstream manner. Travel time from As Samra to KTR is normally about 18 hours (Harza, 1996). During this relatively short period, very little organic nitrogen is expected to be converted to an inorganic form (Ammonium). As such, the sum of Ammonia-N and Nitrate-N is expected to remain relatively constant moving downstream. Inputs of nitrogen from side wadis would change the mass balance. Little denitrification is expected to occur in Wadi Zarqa as it is fairly well aerated for most of its course (Harza, 1996).

Within KTR, consumption of ammonia and nitrate by algae and aquatic vegetation is expected to reduce total nitrogen. In addition, some denitrification will contribute to the loss of nitrate. Nitrate is expected to dramatically decrease between inflow and outflow from KTR or any proposed reservoir as it has historically through KTR. This response is demonstrated in Figure IV.8.

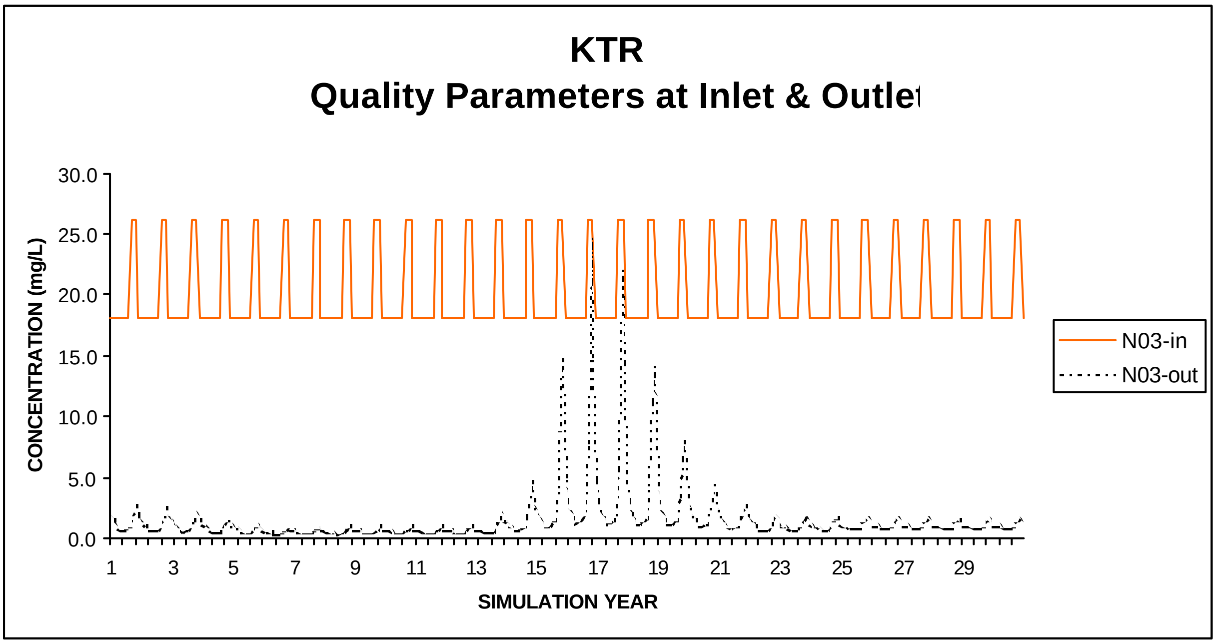

Figure IV.8. Projected Nitrate concentration, in KTR inflow and outflow (Scenario C(1))

Reservoir level has an impact on Total nitrogen and nitrogen form. As reservoir levels decrease, nitrate reduction within the reservoir lessens, as demonstrated in simulation years 15 to 17 in Figures IV.9. and IV.10, due to lower detention time.

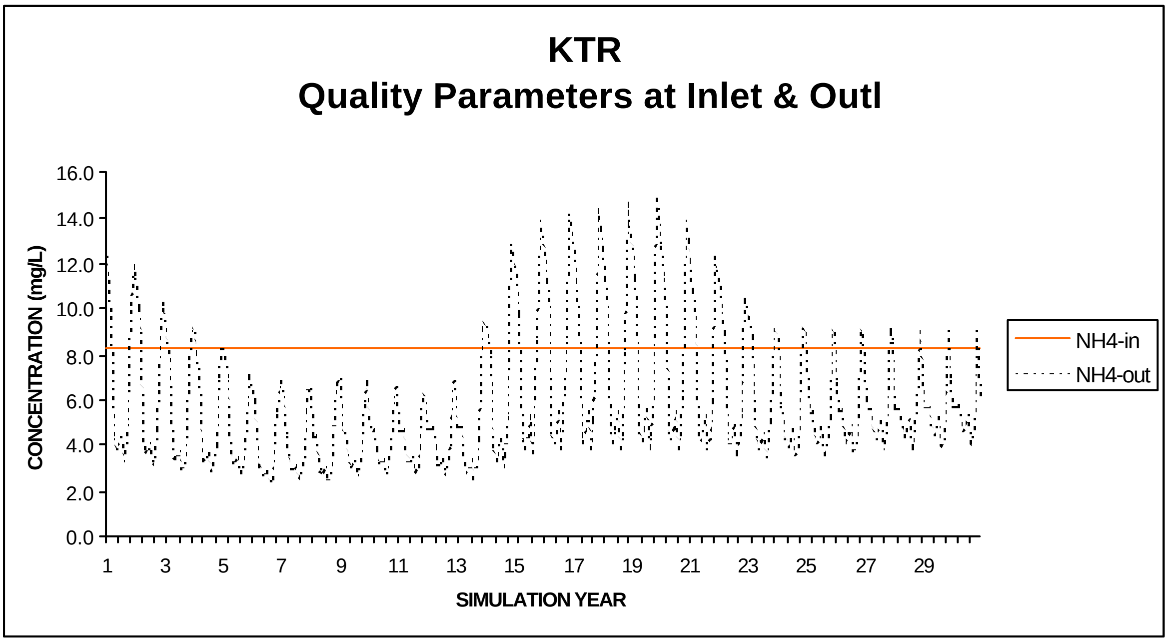

Figure IV.9. Projected Ammonium concentration, in KTR inflow and outflow (scenario C(1))

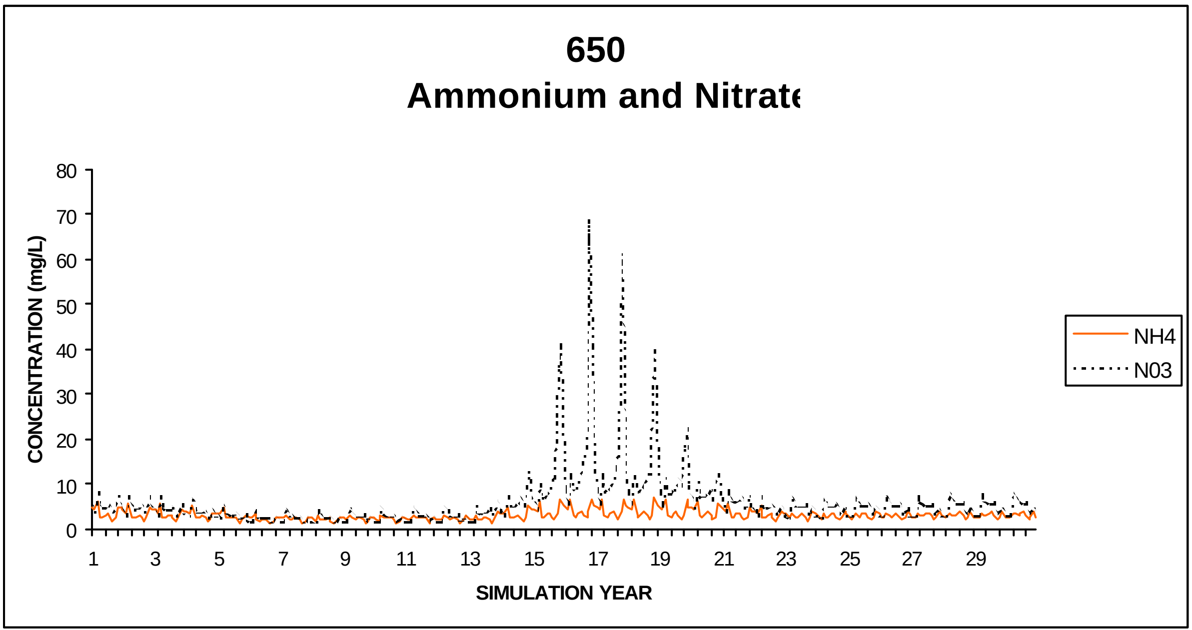

Figure IV.10. Projected Ammonium-N and Nitrate-N concentration at station 650 (scenario C(1))

IV.3.4. Fecal Coliform Count

Fecal coliform levels from As Samra will be lower once the new facilities are developed. However, the contamination of the water in the wadi from sources other than the wastewater treatment plants, will continue. As reflected in Figure IV.11, the fecal coliform levels in the water entering KTR will be elevated in the winter season. The fecal coliform levels in the discharge are much lower, unless the reservoir is drawn down, as is the case in simulation years 15 through 21. During such periods, the fecal coliform levels passing through the reservoir are elevated, as demonstrated in Figure IV.12. The predicted ranges of fecal coliforms upstream of KTR, at the outlet, and downstream of the reservoir, are shown in Figure IV.13. Despite the completion of As Samra, the levels in the wadi upstream of the reservoir remain high because of other contamination sources. The reservoir does, however, significantly reduce these. The predictions also reflect the expected contamination from the side wadis downstream.

Where the demands downstream dictate that the reservoir is consistently drawn down, the lowering of the fecal coliform levels passing through the reservoir is less effective, as shown in Figure IV.14.

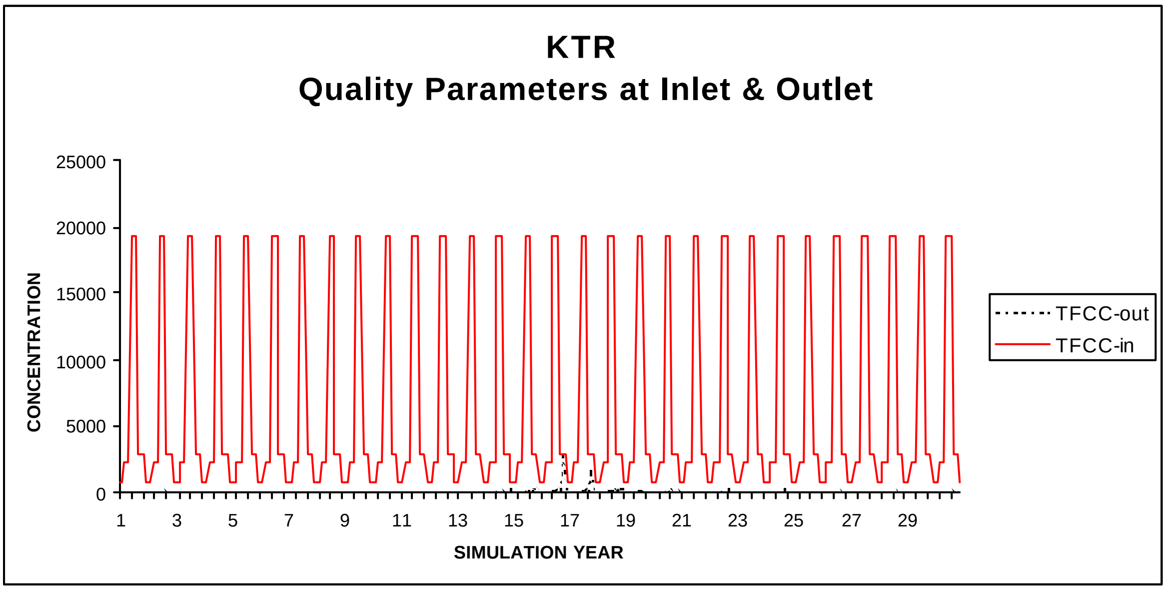

Figure IV.11. Projected Fecal Coliform Concentration, in KTR inflow and outflow (scenario C(1))

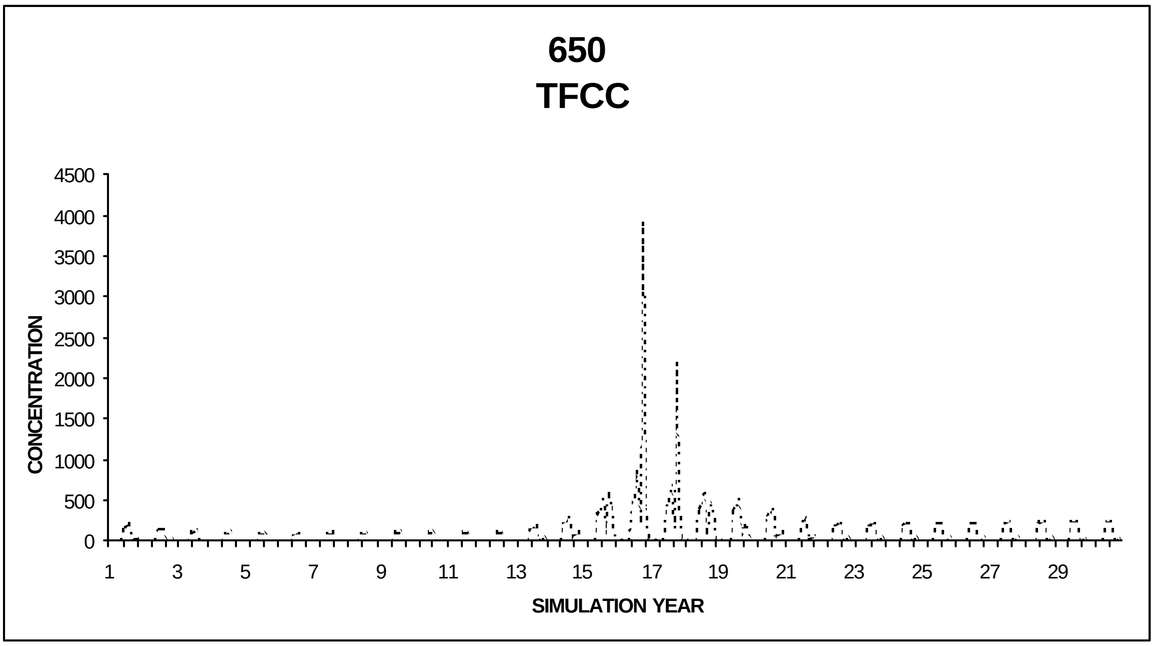

Figure IV.12. Projected Fecal Coliform Count Concentration at station 650 (scenario C(1))

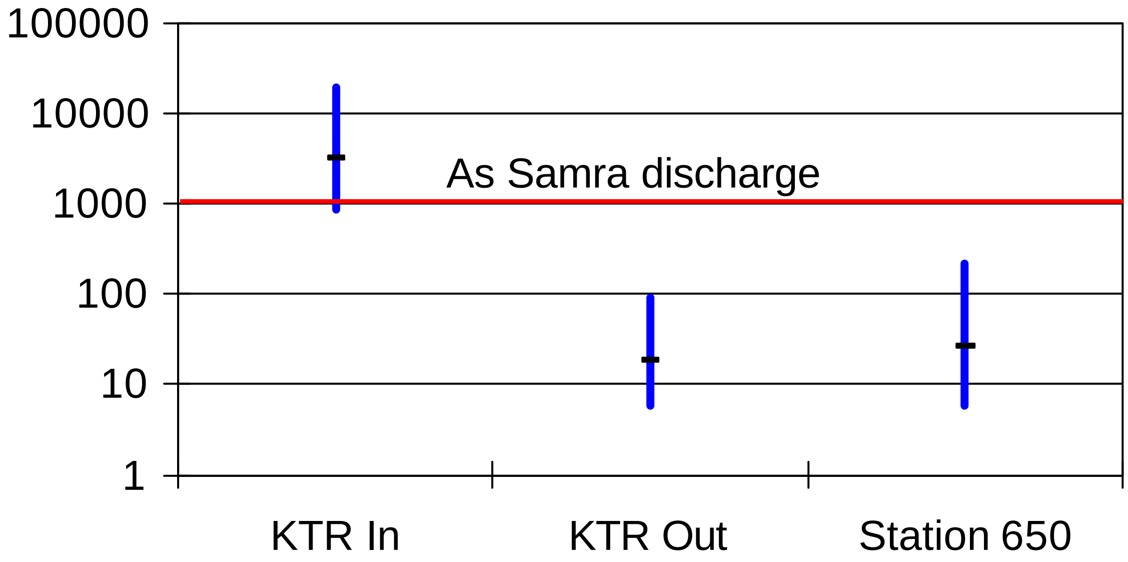

Figure IV.13. Predicted range and geometric mean fecal coliform count in Wadi Zarqa with new As Samra facility developed

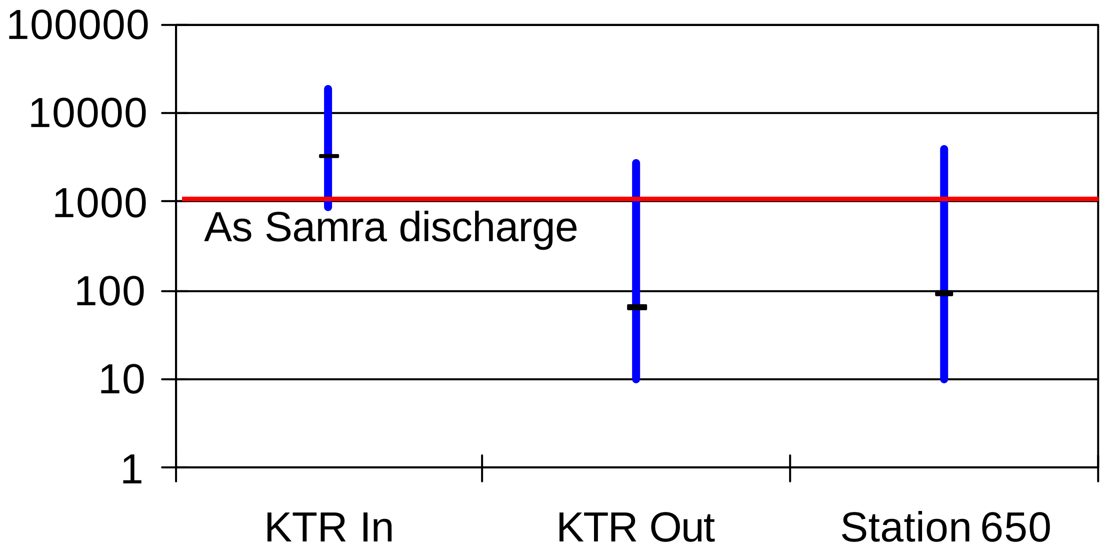

Figure IV.14. Predicted range and geometric mean fecal coliform count in Wadi Zarqa – KTR drawn down

IV.3.5. Total Suspended Solids (TSS)

Total suspended solids (TSS) can present a problem for irrigated agriculture, especially for drip irrigation, in the form of physical clogging. Suspended solids should be analyzed to determine their composition between inorganic and organic material.

Physical clogging problems can also be exacerbated by bacteria. While bacteria indicates a potential biological clogging problem, certain bacteria may also produce iron and manganese oxides also known as iron ochre, which is a combination of the iron oxide precipitate and filamentous algae.

Physical clogging potential is addressed by properly designed filtration systems, ranging from media to disc to screen filtration systems or combinations of these. Media filtration is almost always required for surface water sources. Table IV.3 shows clogging potential for drip systems

Table IV.3. Relative clogging potential of irrigation water for drip systems

	Clogging Hazard, based on concentration		
Factor	minor	moderate	Severe
Physical			
Suspended Solids, mg/l	<50	50-100	>100
Chemical			
Ph	<7.0	7.0-8.0	>8.0
Total Dissolved Solids, mg/l	<500	500-2000	>2000
Manganese, mg/l	<0.1	0.1-1.5	>1.5
Iron, mg/l	<0.2	0.2-1.5	>1.5
Hydrogen Sulfide, mg/l	<0.2	0.2-2.0	>2.0
Hardness	<150	150-300	>300
Biological			
Bacteria (mpn)	<10,000	10,000-50,000	>50,000

In the case of the Amman-Zarqa basin, there is not enough data at higher flows to develop a sediment concentration versus discharge relationship, therefore, it was not included in the modeling exercise. As shown in Figure IV.15, the TSS levels drop significantly in the reservoir (on average < 30-mg/l), which, according to Table IV.3, presents a minor potential for clogging. However, the TSS levels rise again as the water flows downstream, most likely due to scouring and discharge from the side wadis. The reported problems with TSS (JVA - Middle Directorate, 2000) appear to be due to the increased levels during conveyance from the dam to the diversion points, and when the residence time in the reservoir is low. As shown in Figure IV.16., although the average TSS levels are below 50 mg/l, there are periods when this level is exceeded.

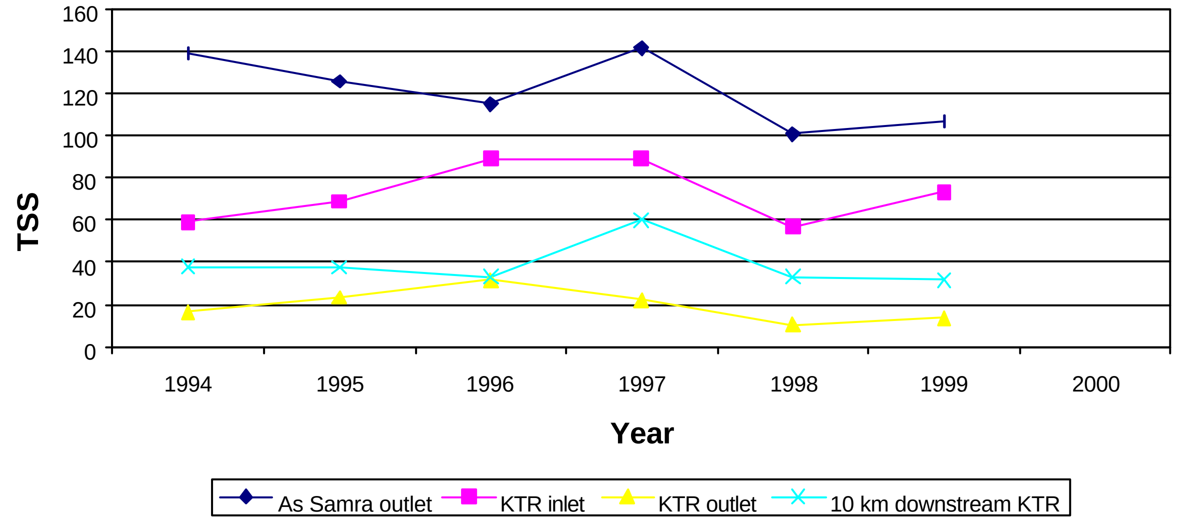

Figure IV.15. Summary of TSS levels between As Samra and the Jordan Valley.

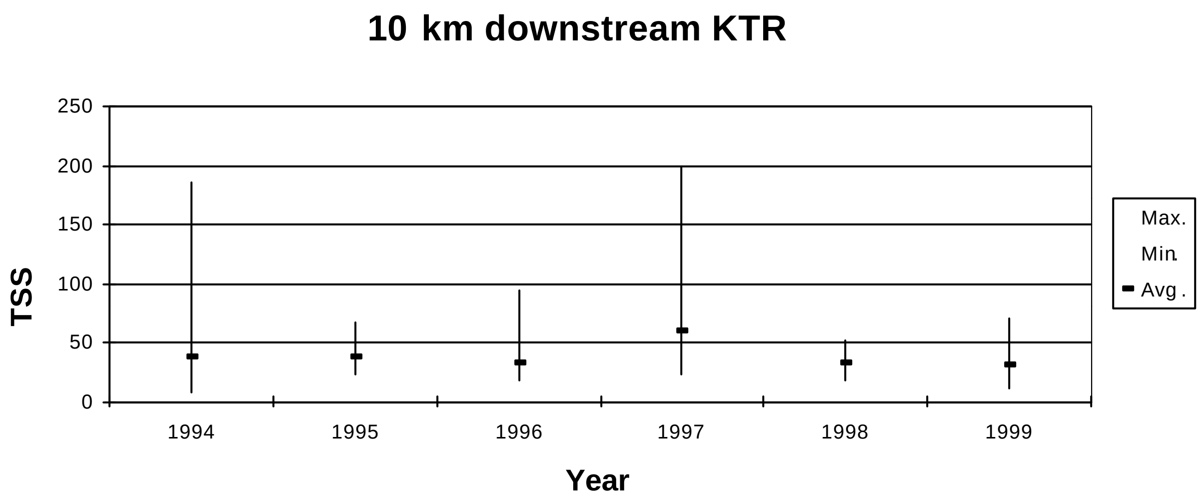

Figure IV.16. Ranges of TSS levels downstream of KTR.

Due to the presence of KTR and it's sediment trapping function, TSS levels at the diversion points are not expected to increase significantly with increasing As Samra flows, especially if the suspended solids are primarily of mineral composition with a specific gravity greater than 1.0. If the solids have a substantial organic fraction, these may be transported downstream. This can be considered a BOD load. Much of this organic load would be reduced by natural in-stream processes and by reduction of BOD in KTR (Harza, 1996). The implementation of the new facilities at As Samra will reduce the BOD and, therefore, reduce the TSS levels. KTR will continue to reduce BOD (Harza, 1996). TSS will remain an issue at the field level, which will need to be addressed by either filtration systems or the management of filtration systems.

IV.4. SENSITIVITY ANALYSIS

Following development of the scenario timeframes, as discussed above, selected scenarios were further analyzed. This analysis included:

- Impact of increased storage capacity; and
- Impact of expected seasonal variation in water supply.

IV.4.1. Increasing Storage Capacity

As further options, or water demands, are developed in the Amman-Zarqa basin and Jordan Valley, and the King Talal Reservoir gradually losses capacity to sedimentation, the need for additional storage may become necessary. However, as reclaimed water becomes more dominant in the hydrology of the basin, the supply will be more reliable, although not necessarily at the time when required.

Opportunities for increasing storage capacity

Opportunities to enhance storage capacity in the Basin and Jordan Valley include:

- the existing Karameh Reservoir,
- an in-stream dam downstream of the existing KTR,
- groundwater recharge in the Jordan Valley, and
- off-stream storage in side wadis in the Jordan Valley.

With the exception of the off-stream storage, these opportunities have been examined as part of the planning process. The 50 M-m^3 Karameh reservoir is intended to store additional water available from the Yarmouk and not water from KTR. Furthermore, the salinization of the reservoir from springs upstream and strata within the reservoir itself make if technically challenging to ensure a water supply suitable for irrigation.

The opportunity to develop a further in-stream dam on the Zarqa has been previously considered, although no studies appear to have been conducted. Examination of existing contour maps suggest that a 85-m high dam upstream of Tal Al-Dahab weir may result in a reservoir capacity of 22 M-m^3. No geological or geotechnical assessment has been done.

The investigations into the groundwater recharge options did determine that there is potential for groundwater recharge in the Jordan Valley (MWI/ARD, 2001g). Such developments could provide additional water resources for dry years.

Considering the above, although detailed feasibility studies are required, there are potential opportunities for developing additional storage, if required.

Impact of increasing storage capacity

For scenario group C, as presented above, the model was used to investigate the impact of incremental increases in storage downstream of KTR, either by developing new facilities or by allowing storage in Karameh reservoir. The results from the analysis of scenario C(1) are summarized in Figure IV.17. Similar results were found for scenarios C(2) and C(3). From this, it can be concluded that the schedules for all "C" scenarios can be implemented more aggressively if the available storage capacity downstream of King Talal Reservoir is increased by 20 M-m^3. However, further increases in capacity appear to have little affect.

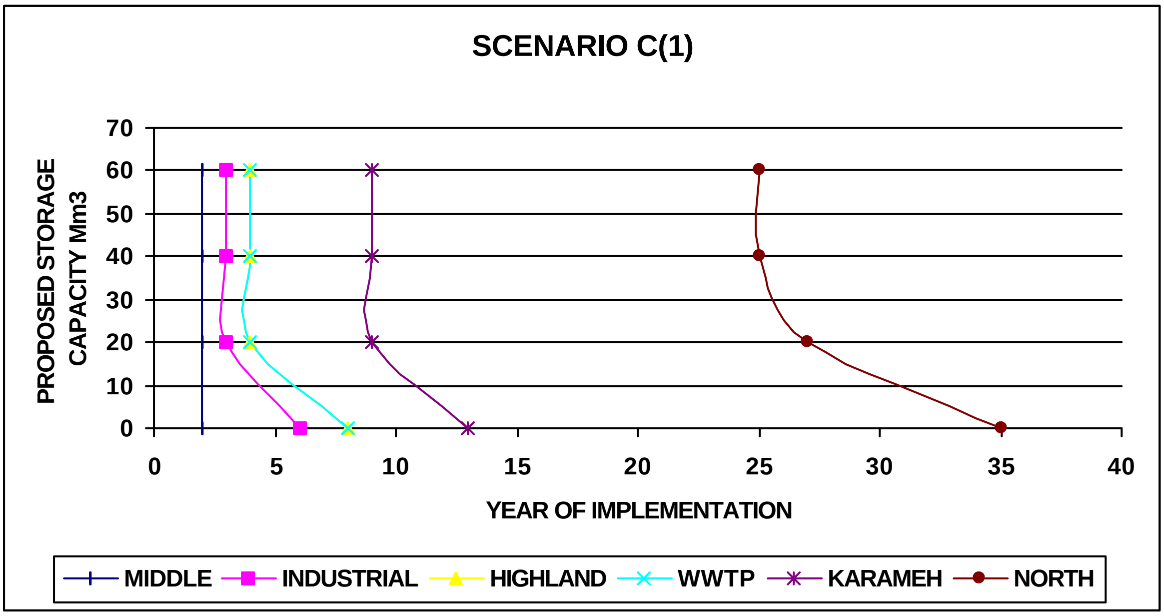

Figure IV.17. Impact of increased storage capacity on scenario implementation schedule

These results are based on the average hydrology adjusted down to 65 percent to allow for the recent drying trends. Further storage could be beneficial to specific options in dry years, especially in the Jordan Valley, to further improve the reliability of supplies. Also, the groundwater recharge in the Jordan Valley could enhance an alternative resource for irrigated agriculture in dry periods.

IV.4.2. Variation in Natural Water Supply

For scenario D, thirty (30) simulations were run to evaluate the range of expected results over a thirty year planning period. For each simulation run, a different synthetically generated flow series was used to develop a distribution of Basin water shortages. From this distribution, the probability of a given shortage for any year was calculated.

The 10 year return period shortages, expressed in terms of volume and percent of demand, for each of the runs are given in Table IV.4. From this, it can be seen that the ten year shortage will, most likely, be less than 12 percent of the demand.

Table IV.4. Ten year return period shortages for 30 runs of a 30 year planning timeframe.

	SHORTAGE	
Run #	M-m3	%
9	15.85	11.30
26	15.85	11.30
18	9.33	10.30
7	14.13	10.10
23	14.13	10.10
10	12.95	9.20
27	12.95	9.20
15	11.93	8.50
11	7.10	5.10
28	7.10	5.10
1	4.35	4.80
14	6.77	4.80
16	4.35	4.80
4	3.36	2.40
20	3.36	2.40
21	2.66	1.90
3	1.66	1.20
19	1.66	1.20
2	0.00	0.00
5	0.00	0.00
6	0.00	0.00
8	0.00	0.00
12	0.00	0.00
13	0.00	0.00
17	0.00	0.00
22	0.00	0.00
24	0.00	0.00
25	0.00	0.00
29	0.00	0.00
30	0.00	0.00

V. OTHER RELEVANT ASPECTS

The storage, conveyance and blending is the backbone of investigating the scenarios for managing reclaimed water in the Amman-Zarqa basin, and the major tool for examining the characteristics and impacts of a scenario is the Excel based model, as presented in Chapter III. However, there are aspects of the storage, conveyance and blending which cannot be addressed by the model, e.g. economics, water quality forecasting under dramatic watershed changes, and water quality forecasting under new complex infrastructure.

This chapter presents the analysis and findings related to storage, conveyance and blending, and then presents an overview of water management requirements for water reuse in the Amman-Zarqa basin.

V.1. STORAGE

This section presents the existing situation with respect to surface storage of reclaimed water in the Amman-Zarqa basin and Jordan Valley, and consideration for additional storage.

In addition to improving the reliability of water quantities being available at the time of demand, storage also plays a vital role in maximizing the benefits from blending. Presently there are two reservoirs that have a role in managing reclaimed water in the Amman-Zarqa basin. These are King Talal and Karameh reservoirs. As mentioned above, both were incorporated in the model. In addition, allowances were made for a further in-stream reservoir in wadi Zarqa.

V.1.1. King Talal Reservoir

<u>Effects of Sediment and Prospects for Removal</u>

Considering its location and storage capacity, the King Talal Reservoir is a very important facility in managing the water supplies (baseflow, surface runoff and treated effluent) from the Amman-Zarqa basin to meet the demands of irrigation in the Jordan Valley, and, to some extent, improving the quality of the water reaching the Valley. The rate of sedimentation within the reservoir will determine the ability of KTR to provide storage in the future.

It is estimated that King Talal Reservoir is sedimenting up at approximately 0.75 M-m^3 per annum (Harza, 1998). The present live storage is approximately 75 M-m^3 compared to a total capacity of 100 M-m^3 in 1981 when the dam was raised. Although there is much discussion with respect to the levels of heavy metals and trace elements in the sediment of King Talal Reservoir, these are not considered to be of major concern (RSS, 1999; and Saidam, 2000).

Dredging of sediment from reservoirs is, generally, an expensive operation, costing at least $US 5 per m^3, and probably more as the sediment in KTR is cemented (Saidam, 2000). In addition, disposal of the dredged material will require hauling out of the wadi, and accounting for the environmental consequences of the heavy metals and trace elements during the removal, transportation and disposal process.

Nutrients

Despite the expected improvements in the quality of effluent discharged into wadi Zarqa (MWI/ARD, 2000b), the phosphorus levels in the Jordanian Standards (15-mg/l) are still well above the level at which the reservoir is considered hyper-eutrophic (>0.1-mg/l) and, therefore, subject to algae blooms (Harza, 1997).

V.1.2. Karameh Reservoir

The Karameh reservoir presents significant opportunities for improving the reliability of water supply for irrigation. In addition to considering this storage in the scenario analysis in Chapter IV, the concerns related to the quality of water in the reservoir were investigated.

The 50 M-m^3 Karameh reservoir was developed to store the excess winter supply available, via the KAC, from the Yarmouk river. This water would then be pumped-back for irrigation in the Karameh Directorate. Realizing that the reservoir site includes soils high in salt, and it is fed by saline springs within and upstream, the operational plan calls for the reservoir to be flushed three times before the stored water would be suitable for irrigation, and, that by maintaining the reservoir at a high stage the ingress of salt can be limited. However, since completion of the dam, the unusually dry conditions have meant that available surplus water in KAC has only allowed the reservoir to be partially filled twice, 15 M-m^3 in 1997 and 30 M-m^3 in 1998. Further experience with operating the reservoir is required before the likely quality of the water from the reservoir can be confirmed.

It has been suggested that the impact of salinity can be reduced by either diverting upstream saline springs or lining the reservoir, or a combination of the two. From the information available, and discussions with the dam tender and the Dams Directorate of JVA, the springs that could be diverted have been diverted. Also, because of the potential for up-lift from a high water table, the relatively large area of the reservoir (approximately 5.0-km^2), and the uncertainty of addressing the problem, lining the reservoir would be technically difficult, expensive (~$5 M, without armor), and of uncertain benefit. Given this, further data and experience are required with the reservoir before the feasibility of such an investment can be determined.

V.1.3. New Storage Facilities.

In addition to the discussion on Karameh dam above, the opportunities for increasing storage capacity are discussed in section IV.4.1.

V.2. CONVEYANCE

The analyses of conveyance includes examination of the prospects for gravity distribution and low-head pumping of reclaimed water to further areas in the Jordan Valley and Wadi Zarqa; gravity conveyance to potential reuse sites below As Samra; assessment of the technical and economic feasibility of diverting the effluent stream around or through the King Talal Reservoir to other storage sites so that more relatively fresh water can be stored in the King Talal Reservoir; and assessment of opportunities for diverting saline springs away from mixing with higher quality water.

V.2.1. Gravity or Low Head Conveyance in the Jordan Valley and Wadi Zarqa

The conveyance of the reclaimed water to other areas in the Jordan Valley and Wadi Zarqa were investigated as part of the relevant options investigations, and are detailed in the Jordan Valley Options Report (MWI/ARD, 2001e), and the Wadi Zarqa Options Report (MWI/ARD, 2001b). From these, and the investigation of reuse for irrigated agriculture in the highlands (MWI/ARD, 2000b), it is imperative that, if the development was to be justified by the returns from irrigated agriculture alone, the capital and operating costs for the conveyance system needs to be very small.

V.2.2. Bypassing KTR

The proposal to have the effluent by-pass the reservoir in a pipeline is aimed at maximizing the quality of the water in the reservoir, and capturing the relative fresh runoff and baseflow from the wadi. The benefit being that this would afford more flexible blending conditions in the wadi.

The costs for developing the required infrastructure will be very large. In addition to a pipeline, the need for storage capacity for the bypassed reclaimed water would necessitate the construction of a further reservoir if the reclaimed water was to be delivered to meet the demands of the Jordan Valley, as it is now.

Furthermore, the quality of the runoff from the basin, which is impacted by the presence of Amman in a large portion of the headwaters, would exclude its use for municipal water supply due to high treatment requirements. If the surface runoff, and possibly the base-flow, is to be captured, a more cost effective option would be to do so before it reaches As Samra, in the upper catchment of the wadi.

V.3. BLENDING (ALTERNATIVES & CONTROL)

There as basically two forms of blending to be considered. One is the real-time blending which occurs at the mixing point where the KTR water meets with the King Abdullah Canal (KAC), and the other is seasonal distribution of available fresh water (KAC) to areas that have been primarily using KTR water.

For the real-time mixing, the basic operating procedure at this time is to add the KTR water to the KAC water and meet the demand in part of the Middle and all the Karameh Directorate. With the drought conditions of recent years, the portion of KAC water has fallen to near zero. Considering the demands for municipal water on the KAC water, this situation is likely to persist.

At least until unit dam is constructed, the excess flow of freshwater in the winter will continue to be available> However, if more reclaimed water is used in the drier periods of the year, then the need for fresh, leaching water will increase. This can be offset by leaching with greater quantities of the lower quality reclaimed water.

V.3.1. Potential Changes in Blending Practices

Blending of the relatively saline water from KTR with water from KAC and other sources is an important part of managing the quality of water in the Jordan Valley. Although there is some real-time blending of these water sources, the fresh water for irrigation in the Middle and Karameh Directorates is available in the wetter winter months (MWI/ARD, 2001e), when it is used for leaching, sterilization and, some, crop-water use. During the warmer months, the bulk of the water supplied to these Directorates comes from KTR. On average, the portion of the water supplied from KTR has been greater than 80 percent. It is recommended that this basic operational strategy remain in place, with fresh water being diverted in the winter when there is low demand from other users.

V.4. ADDITIONAL SOURCES OF SALT IN WADI ZARQA

In addition to the effluent from the wastewater treatment plants, there are other sources of salt within Amman-Zarqa basin that contribute to the TDS levels of water reaching KTR. These sources are industrial activity on the upper Zarqa wadi and saline springs. Figure V.1. shows the range of TDS determined by RSS from 1994 through 2000 in the As Samra effluent (sampling site #4), in Wadi Dhuleil immediately upstream of the confluence with Wadi Zarqa (sampling site #5), in Wadi Zarqa downstream of the confluence (sampling site #5.1), and at Jerash bridge (sampling site #7). There is limited data from the sampling site (#6) located wadi Zarqa upstream of the Wadi Dhuleil confluence.

From Figure V.1, the average TDS level in the wadi increases downhill. The increased levels between site #4 and #5, and sites #5.1 and #7 are most likely due to saline springs, with some contribution from evapoconcentration and agricultural return flow. The increased TDS levels between site #5 and #5.1, appears to be a combination of industrial/municipal discharges and saline springs discharging into the upper Wadi Zarqa.

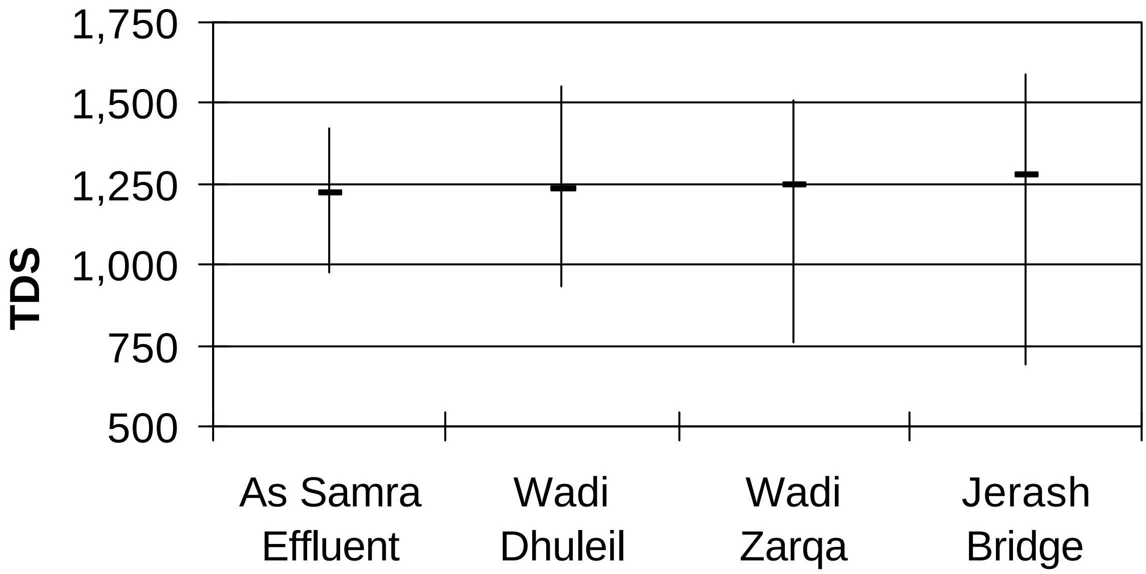

Figure V.1. Ranges of TDS levels along Wadi Zarqa (1994 – 2000)

Although the saline springs appear to be contributing to TDS levels, intercepting the spring discharges and separating them from the wadi discharges is not practical as there is no viable disposal option. Also, the total contribution of salts from these springs is likely to remain constant or decrease. Of more concern, as detailed in "Controlling Harmful Discharges in the Amman Zarqa Basin" (MWI/ARD, 2001i), is the potential increase in industrial contribution to the wadi and/or the sewers. Even at levels that comply with the relevant Jordanian Standards, the TDS in the wadi could be elevated further.

VI. CONCLUSIONS & FURTHER WORK

VI.1. Conclusions

The present and future basin level management, in terms of storage, conveyance & blending, was investigated. The basic methodology included the development of an Excel based “Reclaimed Water Allocation” model (RWAM-AZB), which was used to balance the supplies and demands (existing and future options), and account for the major water quality constituents of interest for irrigated agriculture. In addition, other aspects related to the storage, conveyance and blending were examined.

Allocation of Reclaimed Water

A range of scenarios for allocating expected reclaimed water resources were simulated. These preliminary analyses were used to consider the relative impact of options on each other. The final analysis will be conducted as part of developing the plan for managing water reuse in the basin, and the results will be presented in the final report. Generally, the highlands options, both for agriculture and industry, are relatively small. Their implementation will not have a significant impact on the allocation to the larger demands in the Karameh Directorate or the Northern Directorate. However, should allocations to either of these directorates have to be made before allocating reclaimed water to the highlands, the highlands options could not be implemented until well into the planning period (around year 2020). If both directorates were to be fully allocated, the highlands options could not be implemented until beyond the planning horizon (year 2025).

Water Quality

The TDS and Chloride levels reaching the Jordan Valley from the Amman-Zarqa basin are expected to trend slightly upwards due to the increasing influence of the reclaimed water. Also, the TDS levels of the outflow from the King Talal Reservoir (KTR) are expected to gradually increase relative to that of the inflow. However, should, as expected, the quality of water supply to Amman improves (development of new sources from Zara-Main, Disi and KAC), the TDS and Chlorides will decline.

The total phosphorous levels will continue to be reduced by residence time in the reservoir. In dry periods, where the reservoir is drawn down, the phosphorous levels reaching the Jordan Valley will remain high, although with no direct negative affect. However, the phosphorous levels in KTR will continue to cause algae blooms, which, will contribute to the total suspended solid levels reaching the valley.

The Total Nitrogen levels discharging from As Samra will be reduced and, as is the case now, the Ammonium will decrease and Nitrates increase along the wadi length. Oxidation within the reservoir will cause reduction in both Ammonium and Nitrates, except during periods where the reservoir is drawn down.

With the implementation of the new facilities at As Samra, the fecal coliform levels in the effluent are expected to comply with the Jordanian Standards (MPN 1000). However, the contamination from other sources will maintain higher fecal coliform levels in the wadi. The reservoir will continue to play an important role in significantly reducing the FCC levels. However, as is the case now, the utility of the reservoir is significantly reduced when it is drawn down, thereby, reducing the residence time.

Due to the presence of KTR and it's sediment trapping function, TSS levels at the reservoir outlet are, and are expected to remain, generally low. However, as with other constituents, the TSS rises when the residence time in the reservoir is short. Also, although not related to reclaimed water, the TSS rises between the outlet and the diversion point. In conclusion, TSS will remain an issue at the field level, which will need to be addressed by filtration systems and their management.

Storage

Additional storage facilities that could be utilized for managing reclaimed water in the Amman-Zarqa basin include the existing Karameh dam, a potential site for an in-stream dam downstream of the existing King Talal reservoir (KTR), and artificial groundwater recharge in the Jordan Valley. Increasing surface storage by around 20 MCM, either by using Karameh dam or a new facility, will allow the scenarios to be implemented more aggressively. Further increases in surface storage have little effect.

At this time, the Karameh reservoir is not intended for storing reclaimed water. Furthermore, the elevation of salt levels due to saline springs, the local soils and evapo-concentration, limited the viability of water stored in this reservoir. From the information available, further experience is required with the operation of the reservoir under non-drought conditions, to determine the expected quality of the water.

Artificial recharge of groundwater may present an opportunity to improve, in terms of quantity and quality, shallow groundwater supplies available in parts of the Karameh and Middle Directorates. These resources could be accessed during dry periods when surface water supplies are low.

Conveyance

Enhancement and expansion of the conveyance facilities was examined with regards to supply reclaimed water to the various options investigated, and in managing reclaimed water in the basin. The details for each option are presented in the relevant options report. Unless the reclaimed water is to be used for non-agricultural purposes (industry) or to be exchanged with existing uses of freshwater, the pumping and conveyance costs must be kept to a minimum for any such development to be economically viable.

The proposals to develop major pipelines to carry the reclaimed water from the wastewater treatment plants, down the wadi and past the reservoir, are, because of the volumes involved, very costly. In addition, the benefits, either by reducing the impact on water quality in the reservoir or preventing use of the reclaimed water in Wadi Zarqa, are unlikely to be achieved.

Blending

In addition to the blending of reclaimed water with runoff and baseflow in Wadi Zarqa, the real-time and seasonal blending in the Jordan Valley are important component of water quality management in the Jordan Valley. In recent years, the quantity of freshwater available for blending has been very limited. As reclaimed water becomes more dominant in the basin, the relative portion of freshwater is set to decline. As it is Government Policy not to allocate further freshwater to irrigation, the quantity and timing of freshwater supplies are likely to remain the same, with excess flows in the wetter periods allocate to these Directorates.

VI.2. Future Work

The present and future water quality within the Amman-Zarqa basin is of critical importance to the downstream users. The analysis and assessment described in this document was only possible because of the extensive datasets collected by WAJ, and RSS on behalf of WAJ and JVA. These on-going efforts remain vital to addressing the water quality issues in the basin. The enhancement of monitoring activities, and improvement of information management and dissemination are of a high priority. Further details are presented in the working paper on monitoring and information management (MWI/ARD, 2000c).

In addition to the above monitoring and information management, there is a need to better understand the source and nature of the additional contamination not associated with the wastewater treatment plants. This is particularly true of the microbiological contamination. Rather than including such an effort in a long-term monitoring program, it would be best done over a finite period of up to a year with the objective of identifying the sources of contamination and developing baseline information to access efforts to alleviate this contamination.

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GLOSSARY OF TERMS

Cropped area: The cumulative area of crops planted over a year.

Cropping intensity: Cropped area / irrigated area

Direct Water Reuse: The beneficial use of reclaimed water that has been transported from the treatment plant to the point of use directly through pipes or in lined channels, without an intervening discharge to a natural water body, such as a stream of pond.

Domestic Wastewater: Wastewater generated in residential and commercial activities, possibly also including minor amounts of industrial wastewater subjected to pre-treatment meeting the requirements of connection to the sewer network issued by the Department of Meteorology and Standards.

Effluent: Flow discharged at the end of a treatment process or a treatment train, which may be suitable for some uses, depending on the level of remaining pollutants.

Food Crops: Any crops intended for human consumption.

Guidelines: Semi-official rules and limits for long-term sustainability of water activities in agricultural, industrial or urban sectors.

Indirect Water Reuse: The use of effluent from a wastewater treatment plant after it has been discharged to a natural water body, such as a stream, pond, or reservoir.

Irrigable area: The area of land that can sustainably be used for irrigation.

Irrigated area: The area of land that is under irrigation.

Recycled Water: Water created as a result of treatment and disinfection of wastewater, and deemed safe for specific, intended uses (defined above). Recycled water is a water resource, with tremendous beneficial usefulness, the only limitations being dependent upon level of treatment, salt content and other characteristics that might restrict it to certain uses.

Reclaimed Water: Synonymous with “recycled water,” and usually used interchangeably. Strictly speaking, “reclaimed” water originates at a central water reclamation facility, whereas “recycled” water originates onsite. This is especially true at an industrial site recycling its own water over and over again, for example in a cooling tower.

Regulations: Legally adopted, enforceable rules and limits for water reclamation activities, with measured penalties provided for violations.

Standards: Limits on specific parameters, set for the purpose of protecting the public health, or the environment. Standards are usually incorporated in regulations. Sometimes "standards" are used synonymously with "regulations".

Unplanned Reuse: Withdrawal by gravity or pumping from wadis where a major portion of the flow is effluent from an upstream wastewater treatment plant. This is an unauthorized use of wastewater, even if at the point of discharge, effluent quality meets the standards in effect.

Unrestricted Use: Use of pathogen-free water for all non-potable uses, including irrigation of food crops consumed without further processing. The restriction on potable use still applies, unless treatment includes membrane filtration and fail-safe provisions against survival of microorganisms and trace organic compounds.

Use Area: Any area where reclaimed water is used, with defined boundaries.

Wastewater: Polluted and contaminated sewage, resulting from residential, and industrial uses of water and carrying waste products, including organic materials, inorganic compounds, and various microorganisms. Wastewater, *per se*, is not a water resource for any beneficial uses, unless treated appropriately and converted to "recycled water".

Wastewater Reuse: Unregulated (illicit) use of wastewater or inadequately treated wastewater effluent for irrigation of crops or for any other uses.

Water: All usable water, including surface runoff, groundwater, brackish, and recycled water, but excluding contaminated, saline, and raw wastewaters, which are unsuitable for beneficial use.

Water Reclamation: The process of salvaging usable water from wastewater by mechanical treatment (physical, chemical and biological) and disinfection, salt removal, or natural processes.

Water Recycling: Synonymous with "water reuse." This term is used in some regions exclusively in reference to all water reclamation and reuse activities, because of the positive public image of “recycling” as an environmentally good deed.

Water Reuse: The intentional, planned reclamation of water from wastewater and its conveyance and distribution to agricultural, industrial, and other sites, where it can be put to beneficial use. The terminology “wastewater reuse” is avoided in this document to prevent confusion with the unplanned, unauthorized uses of inadequately treated waste and its unwholesome consequences.

APPENDIX A
RECLAIMED WATER ALLOCATION MODEL FOR THE AMMAN-ZARQA BASIN (RWAM-AZB) - TECHNICAL REFERENCE

Reclaimed Water Allocation Model
Technical Reference

Developed by Associates in Rural Development
For
Ministry of Water and Irrigation
As part of
Water Resource Policy Support Project

Garry Grabow
Assistant Professor
Biological and Agricultural Engineering
North Carolina State University

March 2001

The Water Resource Policy Support activity is supported by the United States Agency for International Development (USAID) through a contract with Associates in Rural Development Inc (ARD): USAID/ARD Contract No. LAG-1-00-99-00018-00, Delivery Order No. 800

Abstract

This technical reference is a companion to the Reclaimed Water Allocation Model for the Amman-Zarqa Basin (RWAM-AZB). This model is designed to predict water supply reliability and water quality for various water reuse scenarios in the Wadi Zarqa Basin and Jordan Valley.

The methodology, logic and governing equations used in the model are detailed in this reference. Flow and water quality components in the model are addressed.

Water supply and demand figures used in the planning model are presented. These figures include current demands for agriculture, and future demands for agricultural, industrial, and groundwater reuse options. The synthesis is detailed and figures and tables showing current and future agricultural and industrial water demand. Modeling of lake evaporation and channel losses is also explained.

Water quality modeling is divided into streamflow and reservoir modeling. Further differentiation is given between reactive or decaying water quality variables, and conservative variables. For streamflow modeling, derivation of first order rate constants is explained and k values are given. Rate constants based upon mass balance principles are derived for reservoir modeling.

Table of Contents

I. INTRODUCTION

The Reclaimed Water Allocation Model for the Amman-Zarqa Basin (RWAM-AZB) is designed to evaluate various water reuse options in the Zarqa River Basin and Jordan Valley, in support of the water resource policy support project led by ARD. The model predicts water quality, and water supply status under various water supply and demand scenarios, and under different blending alternatives on a monthly time step. The water reuse planning model is comprised of a flow component and water quality component. The water quality model uses information generated from the flow model.

This technical reference is a companion to the User's Manual, and details the methodology, background and equations that are used in the planning model.

II. FLOW MODEL

The flow model uses supply (monthly streamflow and As Samra discharges) and demand (agricultural and industrial, lake evaporation, and channel losses) to determine end of month storage and flow at various locations along the Zarqa River. Refer to Figure V-1 for a flow chart of the flow model. Flow stations are shown in Figure V-2 of the flow model component.

II.1. STREAMFLOW

Either historic or synthetic monthly streamflow may be used with the planning model. The historic series is from 1969 to 1999, while synthetic flows are generated for a 30 year period. In addition, the model has an option to use the long-term average monthly flows throughout the simulation period. Both historic or synthetic flows may be scaled to help evaluate various scenarios under drought conditions.

II.1.1. Historic

Historic streamflow data for station 0060 from 1969 to 1999 collected by MWI is contained in the spreadsheet model. As Samra discharges were subtracted from flows at station 0060 to reflect "natural" flow. These historic natural flows can then be used with future As Samra

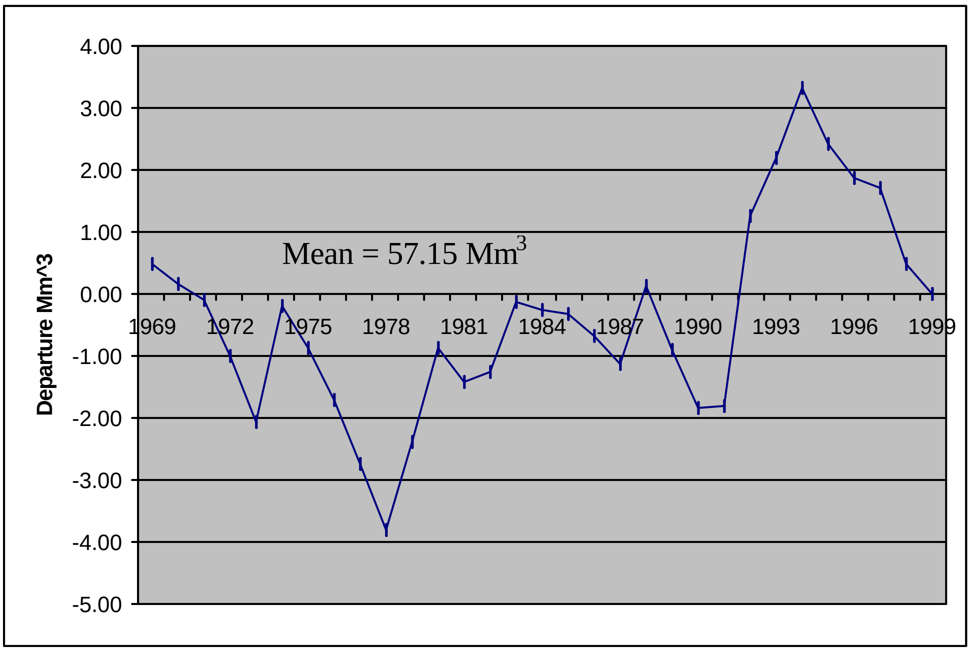


Figure II-1. Cumulative Departure from Mean, Wadi Zarqa without As Samra Discharge flows and various demands to evaluate the impact of future scenarios using the historic flow series. This historic period of record contains both high and low flow periods. This can be seen in Figure II-1 upward and downward trending lines respectively.

Another option allows for the use of average monthly historic flows to be used throughout the simulation period. This allows for scenarios to be compared under "average" streamflow conditions, although streamflow variability is dampened out by averaging.
The other streamflow input used in the model is Wadi Sleyhi, a direct tributary to KTR. Data for JVA station 200 on Wadi Sleyhi is available for 1992 to 1998. Flow at station 200 was correlated with flow at station 0060 in order to fill missing data at 200 when using historic flow, or to make flow consistent with that of station 0060 when using a synthetic flow series for station 0060. The following relationship was used for estimating Wadi Sleyhi flow at station 200:

$$Q_{200} = 596.6 Q_{0060}{}^{0.492} \qquad \text{(II-1)}$$

where Q_{200} and Q_{0060} are monthly discharges in cubic meters for stations 200 and 0060 respectively. The correlation is shown in Figure II-2.

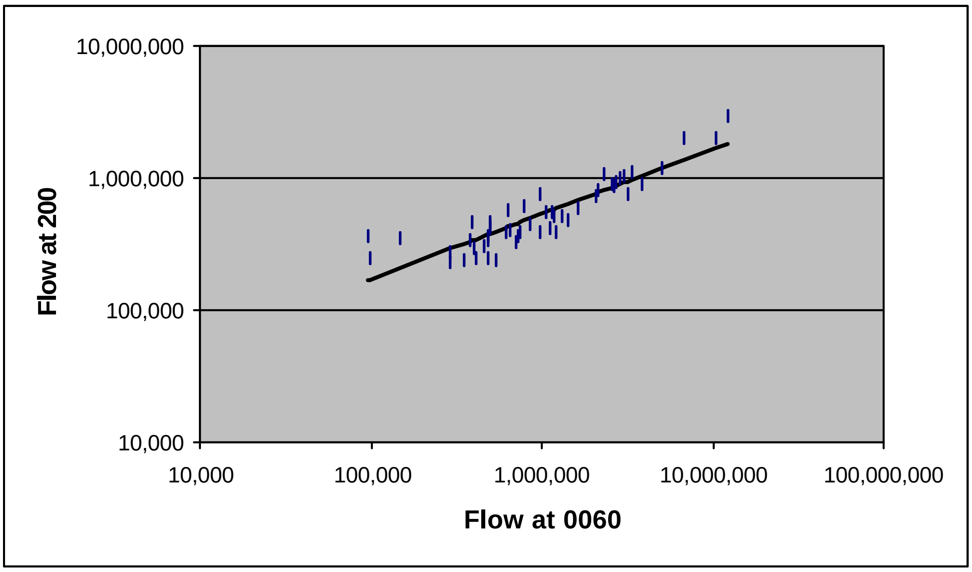


Figure II-2. Correlation between Station 200 on Wadi Sleyhi and Station 0060 on Wadi Zarqa

II.1.2. Synthetic

Monthly synthetic flows were generated for Station 0060 using historic streamflow data. Data from 1969 to 1999 were used to generate statistics that were then used to develop the synthetic series. With a synthetic flow generator, one can generate as many flow series as desired of any desired length. Each series will be different from the next, but will be statistically similar to the historic series, and thus behave as the historic series.

II.1.2.1. Statistical Analysis

The procedure used follows Lindsay et al, (1975) and Salas (1980). A seasonal model was used with months as the seasons:

$$Q_{i,j} = \overline{Q}j + \boldsymbol{r}_j \frac{\boldsymbol{s}_j}{\boldsymbol{s}_{j-1}} (Q_{i-1,j-1} - \overline{Q_{j-1}}) + t_i \boldsymbol{s}_j \sqrt{1 - \boldsymbol{r}_j^{\,2}} \qquad \text{(I-2)}$$

where $Q_{i,j}$ =synthetically generated flow for year i, month j

$\overline{Q}_j$= mean flow for month j

ρ_j = lag 1 correlation coefficient between Qj and Qj-1

σ_j = standard devation of flows for month j

t_i= random variate t, selected randomly from a t distribution.

The first term in Equation (I-2) is the trend, in this case the monthly mean; the second group of terms describes the serial correlation, and the last term is the random error.

Statistically derived estimates of $\overline{Q}_j$, σ_j, and ρ_j, (q_i, s_l, and r_i, and respectively) for each month, j, are given in Table II-1.

Table II-1. Log monthly flow (cfs) statistics for Station 0060 natural flow

Month	q_i	s_i	r_i	Month	q_i	s_i	r_i
Jan	0.38	0.32	0.28	**Jul**	-0.44	0.27	0.90
Feb	0.41	0.36	0.50	**Aug**	-0.48	0.28	0.65
Mar	0.41	0.32	0.55	**Sep**	-0.36	0.22	0.81
Apr	0.09	0.36	0.29	**Oct**	-0.28	0.33	0.39
May	-0.17	0.47	0.59	**Nov**	-0.01	0.35	0.70
Jun	-0.35	0.47	0.86	**Dec**	0.26	0.18	0.37

II.1.2.2. Generation

For station 0060, statistics and equation (II-2) were developed from log-transformed data as the flow data were log-normally distributed. The page “logmonth_stats” in AL0060flow.xls develops the lag-1 correlation coefficient, and the sheet “rand” develops random values for each month to be used as t_i in the above equation.

The lag 1 serial correlation coefficients, ρ_j ,were developed using the method detailed in Salas (1980, chapter 19 “Analysis and Modeling of Hydrologic Time Series”, equations 19.2.13 and 19.2.13.)

A lag 2 (current month's flows depending upon flows from previous 2 months) autocorrelation was also investigated. It was found that this did not improve the model sufficiently to warrant using it in the spreadsheet generator.

The final series of synthetic flows is developed in sheet "generate". The log transformed synthetic flows are untransformed for import into the planning model. Monthly statistics from the synthetically generated flows compare favorably with the monthly statistics from the historic data indicating that the synthetically generated data will behave like the historic data. An example of a synthetically generated series versus the historic series is shown in Figure II-3.

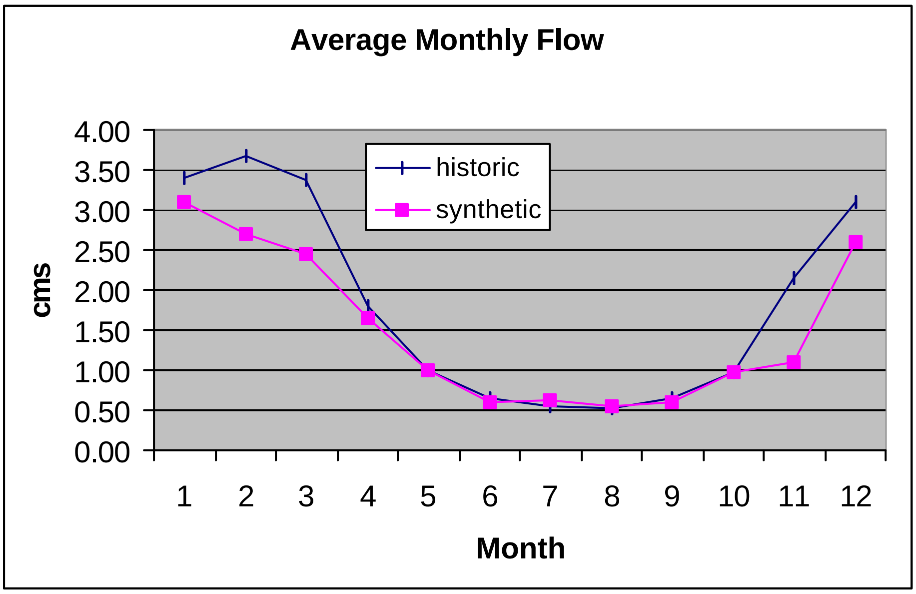


Figure II-3. Comparison of historic and synthetically generated flow

II.1.3. As Samra

As Samra flows were forecast for 30 years into the future (MWI/ARD, 2000a).

II.2. DEMANDS

Water demands comprise agricultural (irrigation) uses, industrial uses, groundwater recharge demands, and reservoir evaporation. See (MWI/ARD, 2001a) for a comprehensive list of current and future water demands. The derivation of these demands are detailed in the options reports for the Wadi Zarqa & from other Amman-Zarqa Sources (MWI/ARD, 2001b); the Jordan Valley (MWI/ARD, 2001c); and the Amman-Zarqa Highlands (MWI/ARD, 2000b).

II.2.1. Agricultural

Agricultural demand is either estimated using climatological data, or based upon actual diversion patterns.

II.2.1.1. Highlands

The water demand for proposed highland irrigated agriculture is based upon crop water demand and a leaching requirement. The crop water use is based upon a mixture of tree crops, annual crops and pasture. See (MWI/ARD, 2000) for agricultural water demand derivation.

II.2.1.2. Wadi Zarqa

Future water demand figures are given in (MWI/ARD, 2001a), and their derivation is presented in (MWI/ARD, 2000). Current diversions of Wadi Zarqa flow for agricultural use is already accounted for in the flow data used in the model, since station 200 already reflects these these diversions.

II.2.1.3. JVA

Jordan Valley demand is expressed as either a current demand or a future demand from the Wadi Zarqa. Current demand is based upon recorded diversions for the middle and south directorates for 1998. Future demand is based upon supplying all of the Jordan Valley demand from the Wadi Zarqa and As Samra outflow.

II.2.2. Industrial

Projected industrial demand for reclaimed water is estimated at 20 M-m^3/yr or 1.67 M-m^3/month (MWI/ARD, 2001a; ARD 2001b).

II.2.3. Evaporation From Reservoirs

Evaporation from reservoirs is based upon the surface area of the reservoir and the average long term monthly evaporation rate. Average long-term monthly evaporation is calculated as

$$E_{res} = 0.7 ET_0 - ppt \qquad \text{(II-3)}$$

where E_{res} is reservoir evaporation, mm, and ET_0 is reference evapotranspiration, mm, and ppt is long term monthly precipitation, mm. ET_0 and ppt are obtained from the CLIMWAT data base (FAO, 1998) for Zarqa. Surface area is determined from calculated end of month storage. For KTR, a volume-surface area table was supplied by JVA. For the proposed additional storage, a volume-surface area relationship was developed using topographic maps.

II.2.4. Channel Losses

Channel losses are modeled by attributing a percentage loss to each reach. Percentage losses can be assigned to Zarqa River reaches from As Samra to KTR, from KTR to the proposed storage, and from the proposed storage to the diversion point.

III. WATER QUALITY MODEL

Ammonium (NH_4^+), Nitrate (NO_3^-), total Phosphorus (TP), fecal coliform (TFCC), total dissolved solids (TDS), and chloride (Cl) are predicted at locations along Wadi Zarqa. These variables were selected due to their potential impact on human health, irrigation water quality, and reservoir eutrophication. Water quality modeling is achieved through empirically derived rate constants for transforming or decaying water quality variables (TFCC, NH_4, NO_3, TP), and through mass balance for conservative variables (TDS and Cl). There are two basic cases of modeling, streamflow modeling and reservoir modeling. Refer to Figure V-3 for a depiction of stream reaches and modeling methods.

III.1. STREAMFLOW QUALITY MODELING

The objective of the streamflow water quality modeling is to predict the concentration of water quality variables at certain locations along the Zarqa. For those water quality parameters that are non-conservative (transform, decay, etc.) the simplest way of modeling is to fit those to an empirical (statistical) model using existing data.

Possible models are zero order (linear) or first order (log-linear) transformation. A first order model was selected. The simple first order model would is:

$$\log(c / c_0) = -kt \qquad \text{(III-1)}$$

where c_0 is initial concentration (upstream at some predetermined point), t is time and c is concentration at the target station as referenced from the upstream station with concentration c_0. Equation (III-1) can be depicted graphically as shown in Equation III-1.

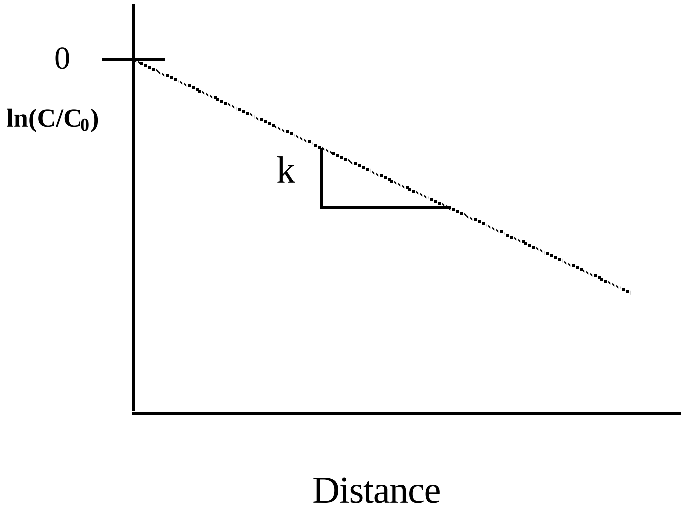


Figure III-1. Graphical depiction of first order rate constant

Distance in km, for instance, can be used instead of time in Equation (III-1). Data was separated into seasons (e.g. spring, summer winter, fall) to investigate whether the relationship in between $\log(c/c_0)$ and distance downstream, i.e, k is different between seasons. In some cases there was a seasonal difference in rate constants. Flow was not a significant factor in determining rate constants. As season is related to flow, it likely explains any impact of flow on the rate constants.

III.1.1. Rate Constants

PROC GLM, a general linear model procedure in SAS, was used to fit the water quality data to the first order rate equation [Equation (III-1)]. Results are shown in Figures IV-4 to IV-7 and in Table III-1. Rate constants used in RWAM were further adjusted to better fit measured water quality data.

Table III-1. First order rate constants

As Samra to storage
rate constants, monthly

	TFCC	NH4	N03	TP	TKN
Jan	-0.0015	-0.0063	0.0209	-0.00669	-0.007
Feb	-0.0015	-0.0063	0.0209	-0.00669	-0.007
Mar	0.0088	-0.0063	0.0255	-0.00669	-0.007
Apr	0.0088	-0.0063	0.0255	-0.00669	-0.007
May	0.0088	-0.0063	0.0255	-0.00669	-0.007
Jun	0.0313	-0.0063	0.0271	-0.00669	-0.007
Jul	0.0313	-0.0063	0.0271	-0.00669	-0.007
Aug	0.0313	-0.0063	0.0271	-0.00669	-0.007
Sep	0.0114	-0.0063	0.0140	-0.00669	-0.007
Oct	0.0114	-0.0063	0.0140	-0.00669	-0.007
Nov	0.0114	-0.0063	0.0140	-0.00669	-0.007
Dec	-0.0015	-0.0063	0.0209	-0.00669	-0.007

600 to 650
rate constants, monthly

	TFCC	NH4	N03	TP	TN
Jan	-0.0015	-0.0328	0.0356	0	-0.00546
Feb	-0.0015	-0.0328	0.0356	0	-0.00546
Mar	0.0088	-0.0156	0.0700	0	-0.00311
Apr	0.0088	-0.0156	0.0700	0	-0.00311
May	0.0088	-0.0156	0.0700	0	-0.00311
Jun	0.0313	-0.01105	0.1079	0	0.00083
Jul	0.0313	-0.01105	0.1079	0	0.00083
Aug	0.0313	-0.01105	0.1079	0	0.00083
Sep	0.0114	-0.02695	0.0721	0	-0.00323
Oct	0.0114	-0.02695	0.0721	0	-0.00323
Nov	0.0114	-0.02695	0.0721	0	-0.00323
Dec	-0.0015	-0.0328	0.0356	0	-0.00546

III.1.2. Conservative Constituents

For conservative water quality variables, concentrations are simply flow-weighted concentrations of any blended water:

$$c_i = (c_1 q_1 + c_2 q_2)/(q_1 + q_2) \qquad \text{(III-2)}$$

Where c_i is the flow-weighted concentration of blended water from sources of concentration and flow c_1,q_1 and c_2, q_2.

To establish c_1 and c_2, correlation between concentration and discharge was investigated. A correlation was used for chloride and TDS. The concept is illustrated in the Figure III-2.

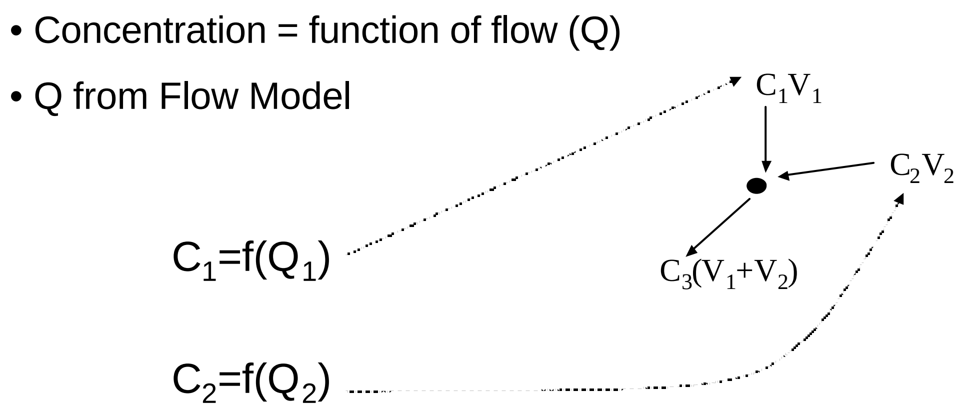


Figure III-2. Graphical depiction of blending of conservative water quality variables

A power model was used to fit concentration to discharge:

$$C = aQ^b \tag{III-3}$$

where C, is concentration, mg/l, and Q is discharge, m^3/month. The parameter estimates for a and b for the different water quality variables is listed in Table III-2.

Table III-2. Regression coefficients for use in Equation (III-3)

Variable	a	b	Comments
Cl	82303	-0.415	Used for 0600 natural flow and station 200
TDS	48635	-0.2815	Used for 0600 natural flow and station 200
NO3-N	6E10	-1,7506	Used only for station 200 inflow to KTR
TP	2013.4	-0.4472	Used only for station 200 inflow to KTR

III.2. RESERVOIR MODELING

Modeling of reservoir water quality is focused upon predicting outflow quality, rather than in-reservoir quality. This is because the concern is water quality delivered to the Jordan Valley rather than on reservoir water quality itself. The reservoir in this sense is more of a "reactor".

Due to this objective, a mass balance model was selected for investigation. This is as selected by Harza (1996), and detailed in Chapra (1997, p. 536). Steady state conditions are assumed to simplify the equation. Historic inflow, outflow, reservoir storage, and water quality data were used to calibrate the model.
A monthly k was determined for each month for each non-conservative water quality variable of interest, by solving for k in the mass balance model:

$$q_i c_i - q_o c_o - Vkc_o = 0 \quad \text{(III-4)}$$

where, q_i is inflow, c_i is inflow concentration, q_o is outflow, c_o is outflow concentration, V is reservoir volume and k is loss rate constant. Equation (III-4) may be read as mass in minus mass out - mass transformed = 0. Solving for k yields:

$$k = \frac{q_i c_i - q_o c_o}{Vc_o} \quad \text{(III-5)}$$

and solving for c_0, outflow concentration:

$$c_o = c_i q_i / (q_o + kV) \quad \text{(III-6)}$$

For total phosphorus, k can be interpreted as a settling rate, since it is primarily exists in adsorbed form on sediment. For decaying or transforming variables it may be interpreted as a decay rate constant. This would apply to NO_3^- a nd NH_4^+.

For conservative water quality variables, expressly Cl- and TDS, outlflow concentration was considered to be that of inflow. In the case of KTR, these outflow concentrations were weighted considering inflow at station 0060 and station 200.

III.2.1. Rate Constants

Reservoir rate constants are shown below in Table II.1.

Table III-3. Reservoir rate constants for KTR and proposed storage (for use in equation (III-6).

Variable	K (mo^{-1})
TFCC	44.106
NH4-N	0.178
N03-N	5.198
TP	0.159
TN	0.13

IV. REFERENCES

MWI/ARD, 2001a. Plan for Managing Water Reuse in the Amman-Zarqa Basin and the Jordan Valley. Draft Report. March.

ARD. 2001b. Options Report on the Wadi Zarqa & From Other Amman-Zarqa Sources

ARD. 2001c. Options Report on the Jordan Valley

ARD. 2000a. Characterization of Wastewater Effluent in the Amman-Zarqa Basin, Water Reuse Component, Internal Draft.

ARD. 2000b. Options Report on the Amman-Zarqa Highlands.

ARD. 2000c. Water Reuse Component. Internal Memo.

Chapra, S. C. 1997. Surface Water-Quality Modeling. WCB McGraw-Hill, Boston.

Harza, 1996. Master Plan and Feasibility Study for Rehabilitation, Expansion and Development of Existing Wastewater Systems in Amman-Zarqa River Basin Area, August.

Lindsay, R.K., Kohler, M.A., Paulhus, J.L.H. 1975. Hydrology for Engineers. McGraw-Hill, New York.

Salas, J.D.. 19__. Analysis and Modeling of Hydrologic Time Series, *in* Handbook of Hydrology, R. Maidment. editor.

V. ADDITIONAL FIGURES

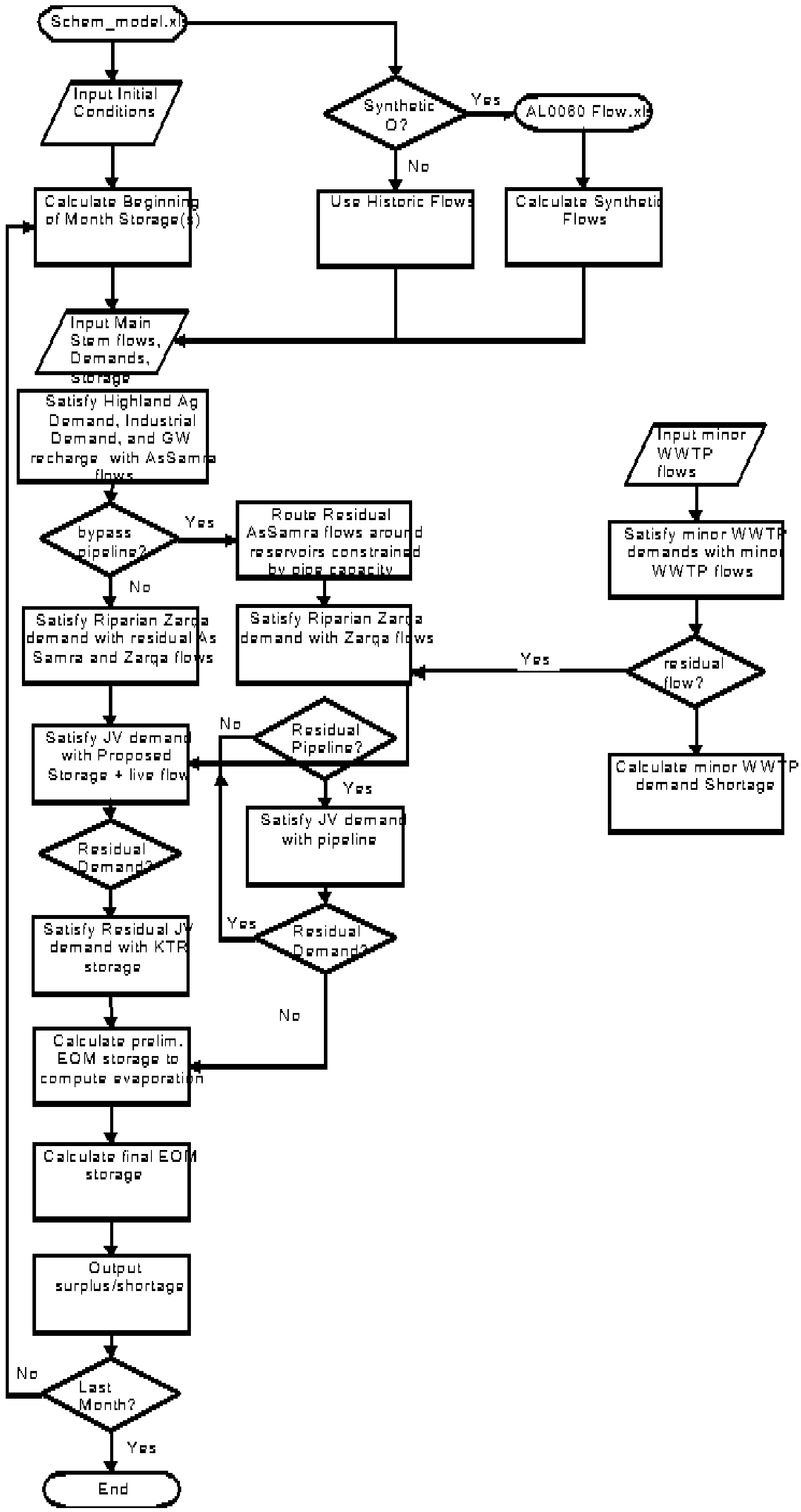


Figure V-1. Flow chart of flow model portion of WRPM

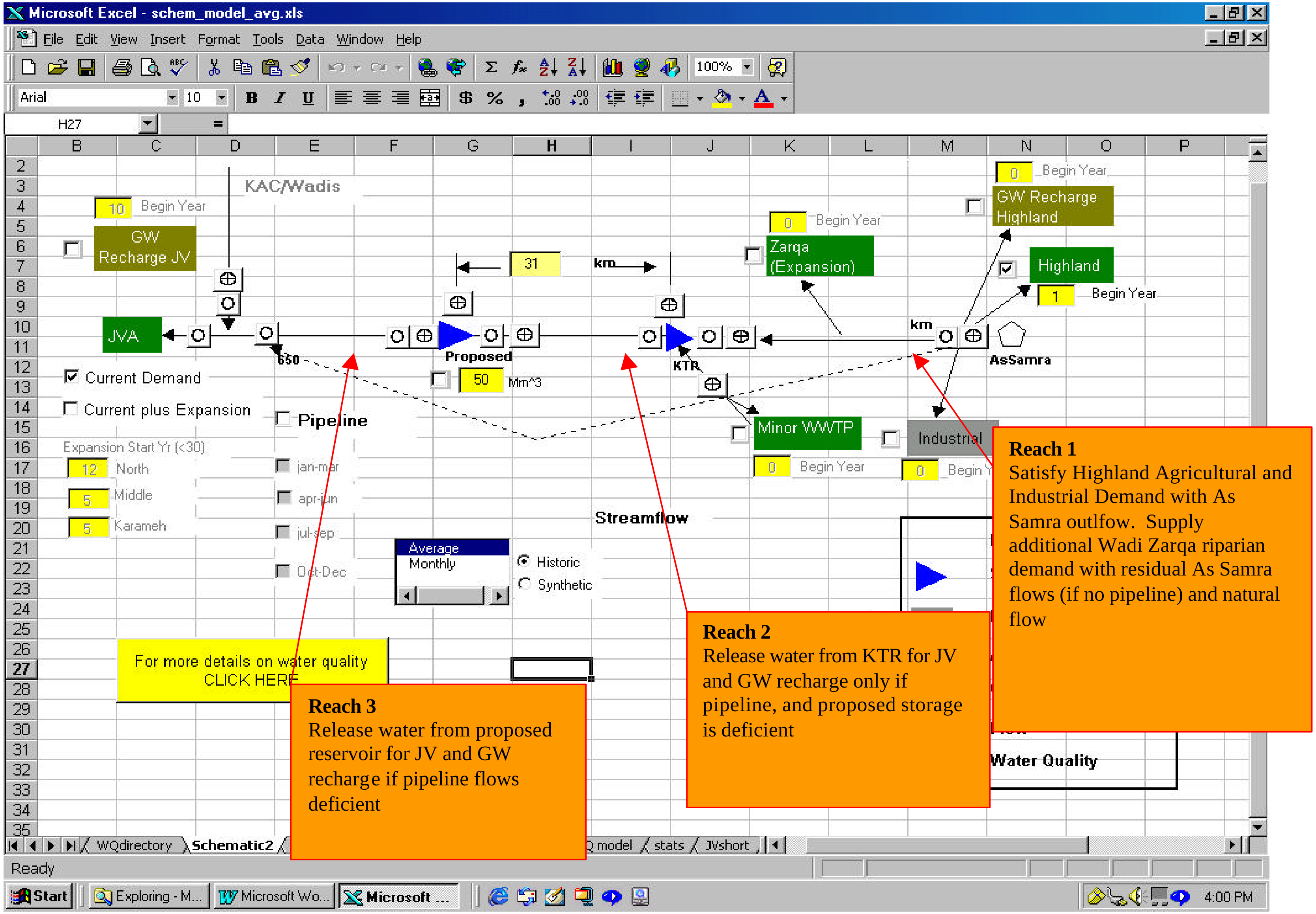


Figure V-2. RWAM Interface with Flow Modeling logic

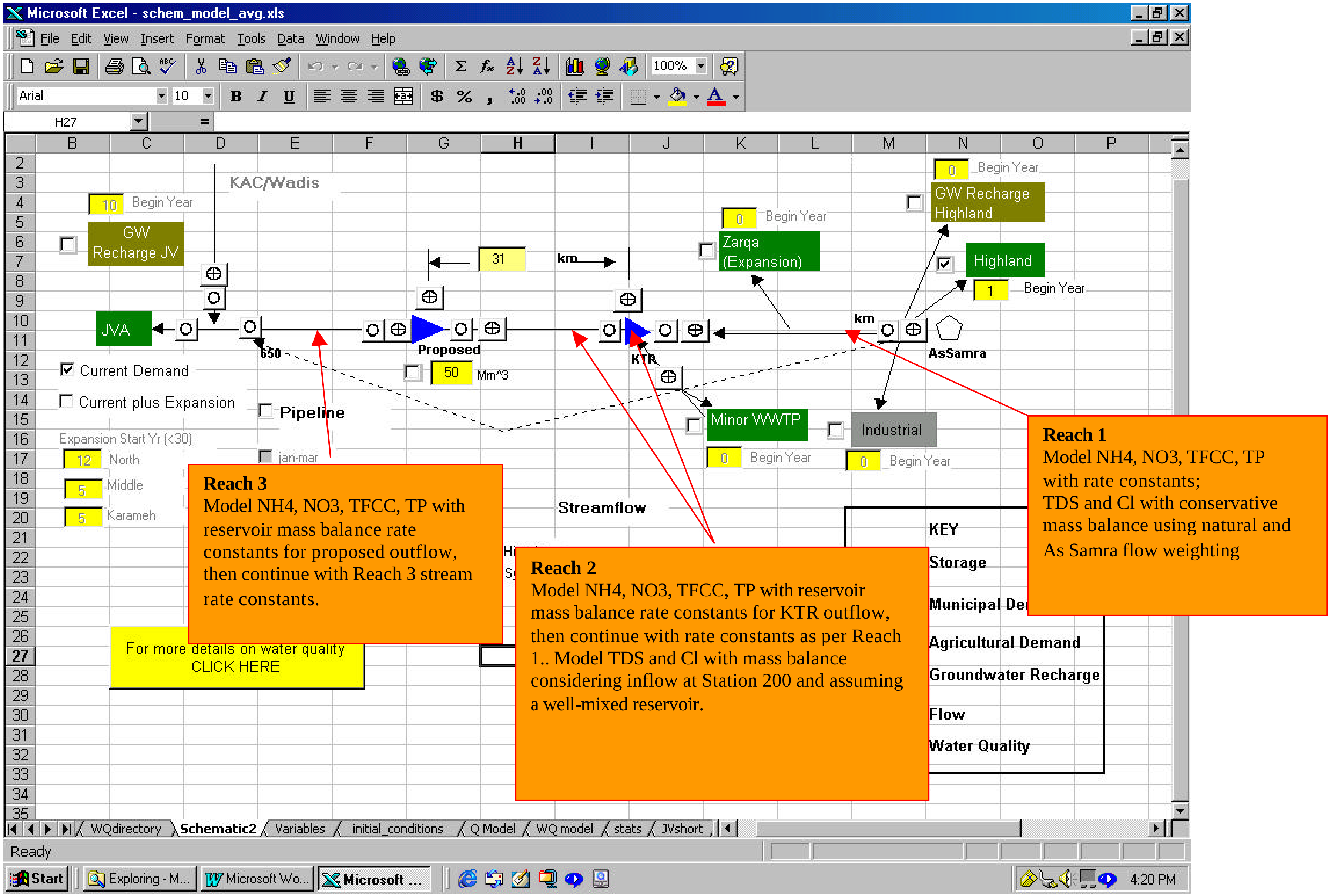


Figure V-3. RWAM Interface with Water Quality Modeling logic

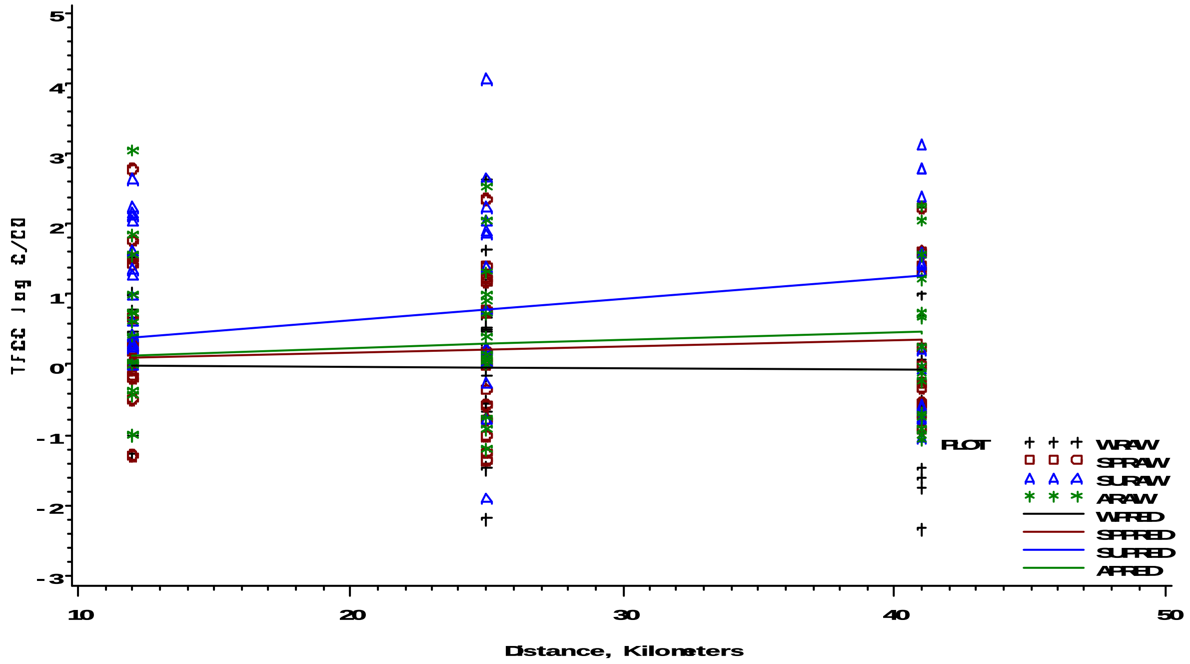


Figure V-4 Relative Concentration of Fecal Coliform versus Distance downstream of As Samra

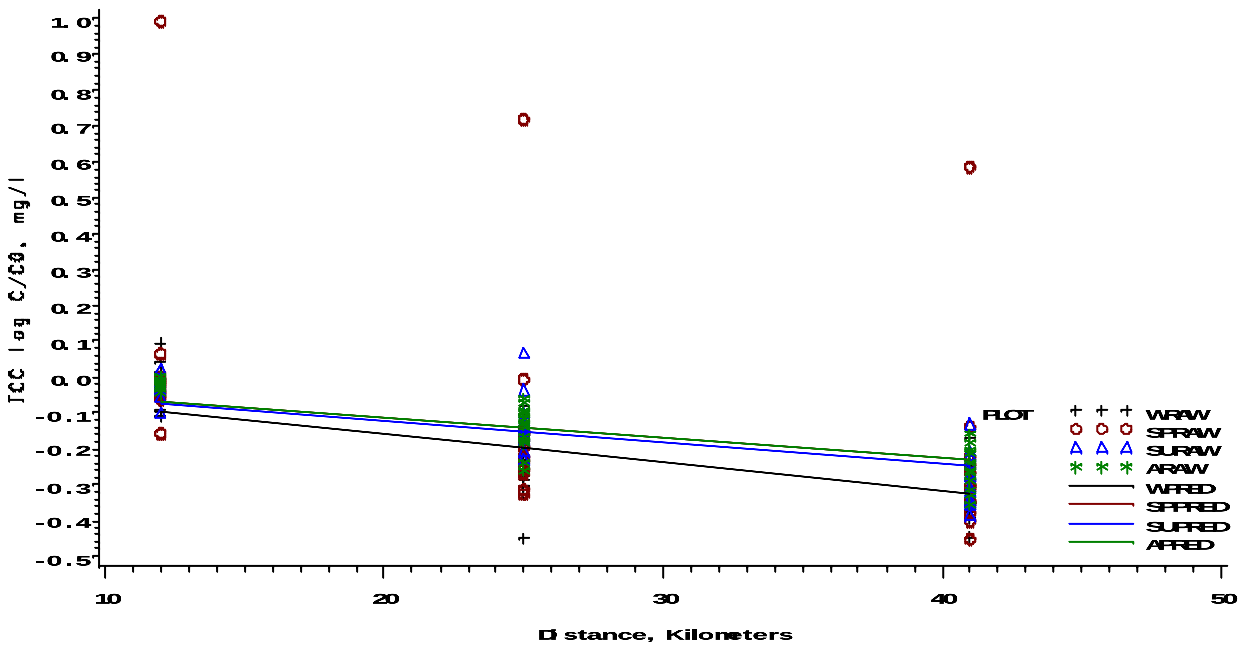


Figure V-5. Relative concentration of NH4-N versus downstream distance from As Samra

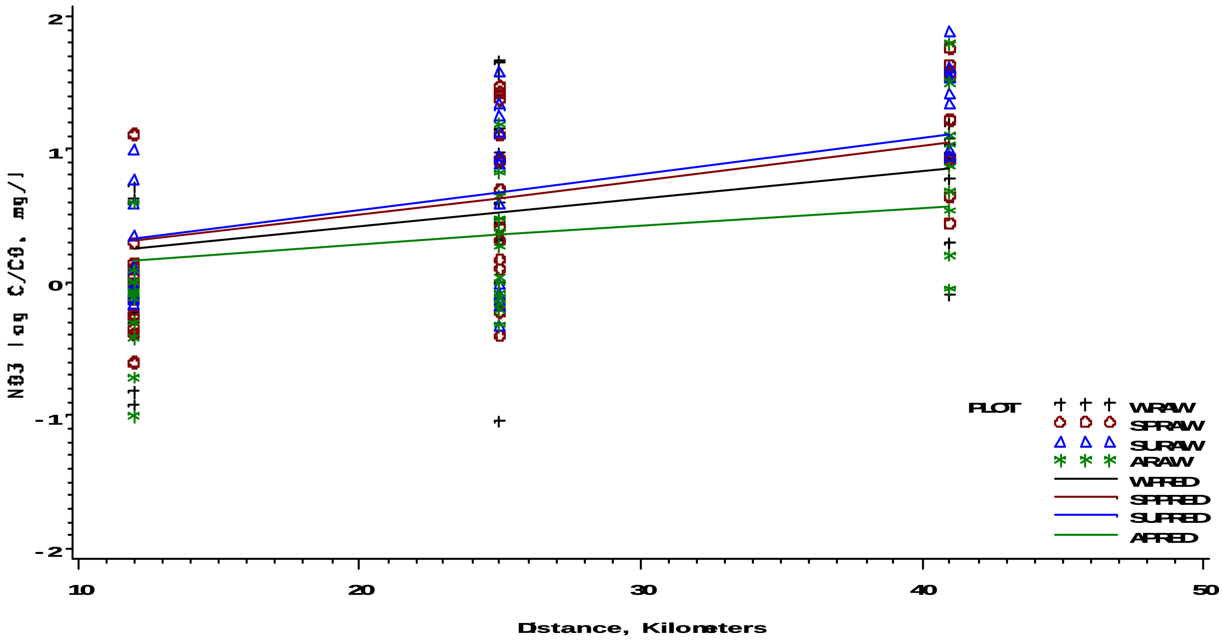


Figure V-6. Relative concentration of N03-N versus distance downstream of As Samra

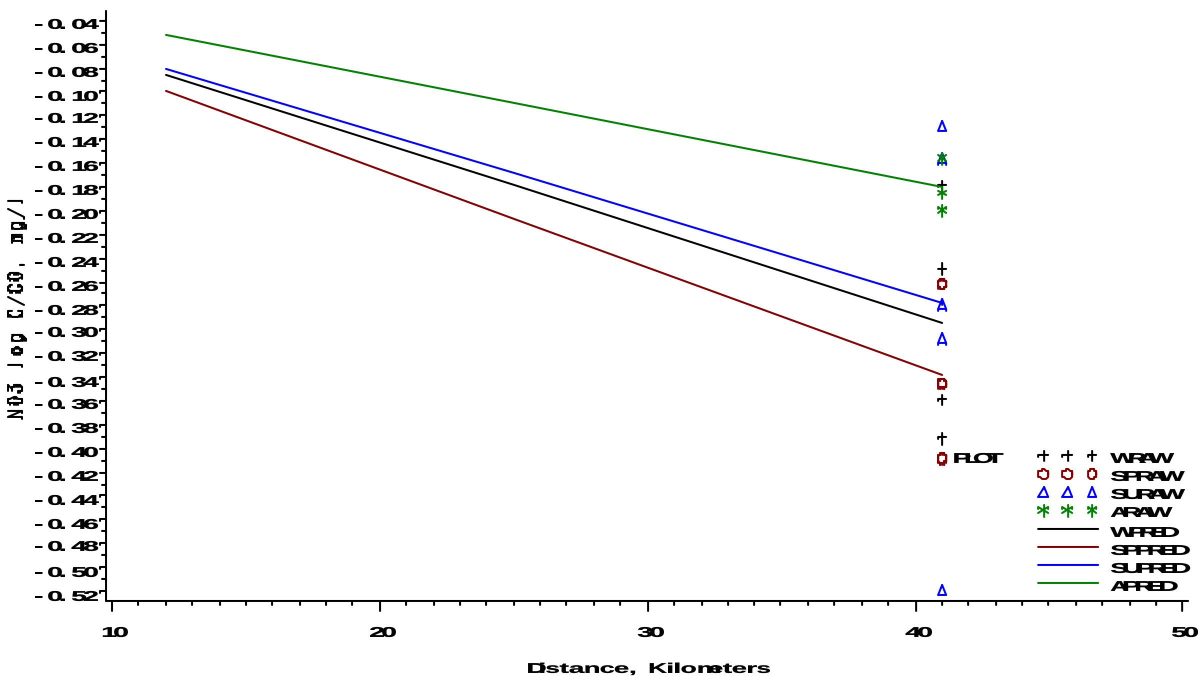


Figure V-7. Relative concentration of TP versus distance downstream of As Samra

APPENDIX B
RECLAIMED WATER ALLOCATION (RWAM-AZB) MODEL USERS GUIDE

Draft

Reclaimed Water Allocation Model (RWAM-AZB) User's Guide

Developed by Associates in Rural Development
for
Ministry of Water and Irrigation
as part of
Water Resource Policy Support Project

Garry Grabow
Assistant Professor
Biological and Agricultural Engineering
North Carolina State University

March 2001

The Water Resource Policy Support activity is supported by the United States Agency for International Development (USAID) through a contract with Associates in Rural Development Inc (ARD): USAID/ARD Contract No. LAG-1-00-99-00018-00, Delivery Order No. 800

Table of Contents

1. INTRODUCTION

The Reclaimed Water Allocation model (RWAM-AZB) was designed to evaluate various water reuse options in the Zarqa River Basin and Jordan Valley, in support of the water resource policy support project led by ARD. The model predicts water quality, and water supply reliability under various water supply and demand scenarios, and under different blending alternatives. The allocation model is developed as an Excel spreadsheet and has a one month time step. The model interface contains objects (input boxes, check boxes, gaging and water quality station icons) that are programmed in Visual Basic. The Visual Basic coding is done primarily for input and output control. The flow and water quality model components are programmed with normal spreadsheet commands.

2. MODEL INTERFACE

The spreadsheet has an interface contained on the first sheet “schematic2”, that shows the nodes and available options. Nodes are shown by a gaging station or water quality station icon, representing flow or water quality output respectively. A plot of flow or water quality resulting from the analysis is generated by clicking on the respective icon.

The options include streamflow input; a KTR bypass pipeline; a proposed additional reservoir; water reuse in the highlands for agriculture, industrial, and groundwater recharge; additional agricultural demand along the Zarqa River; an option to use King Abdullah Canal

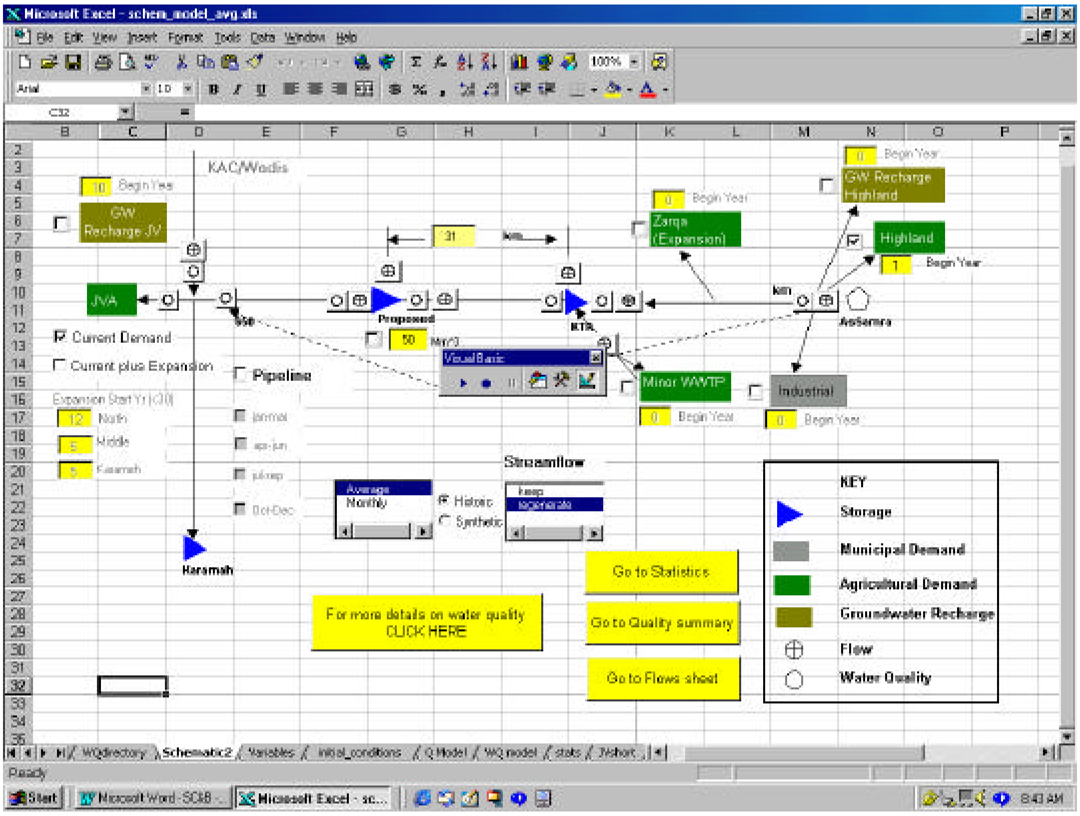


Figure 1. Allocation Model Interface

and side wadi flow; and an option to use current or future Jordan Valley demands.

The user can simply check off those features to be brought into the analysis. In addition, demands can be brought into the simulation at any simulation year. See Figure 1 for the model interface.

2.1. STREAMFLOW

The user may select to use either historic streamflow (1968-1997) or synthetic flow (see technical reference). If synthetic flow is selected, a sub-option allows the user to *keep* the previously generated synthetic flow, or to *regenerat*e a new synthetic flow series.

2.2. KING TALAL DAM BYPASS PIPELINE

A pipeline routing flow around King Talal Dam (KTR) may be invoked by clicking the check box next to the dashed line representing the pipeline. When checked, four sub-option check boxes are enabled representing the periods which to operate the pipeline. This would allow, for instance, to evaluate the impact of routing summers flows around KTR.

2.3. ADDITIONAL STORAGE

Additional storage on the Wadi Zarqa may be evaluated by clicking the check box next to the proposed storage symbol downstream of KTR. The amount of storage is entered by the user into the input box provided.

2.4. HIGHLANDS INDUSTRIAL DEMAND

Industrial demands using As Samra effluent may be evaluated by checking off the box next to the regions in red. These demands represent potential demands of industrial related water use.

2.5. HIGHLANDS AGRICULTURAL DEMAND

To evaluate optional, agriculturally based demands in the Highlands, the user may check the box next to the areas in green. The area of development, in hectares, is entered into the input box.

2.6. HIGHLANDS GROUNDWATER RECHARGE

To evaluate groundwater recharge demands in the Highlands, the user may check the box next to the areas in olive green. The year of implementation is entered into the input box.

2.7. ZARQA DEMAND

Agricultural demand, additional to current demand, can be added to the model by entering the additional hectarage into the input box.

2.8. KAC/WADIS

Flow from King Abdullah Canal and the side wadis that discharge into the canal can be entered into the analysis by checking the check box.

2.9. JVA DEMAND

Two JVA demand scenarios can be evaluated by clicking the appropriate button; current demand and current demand plus expansion. If the current plus expansion check box is selected, North, Middle and Karameh expansions may be selected, and the year of expansion may be entered.

2.10. JVA GROUNDWATER RECHARGE

To evaluate groundwater recharge demands in the Jordan Valley, the user may check the box next to the areas in olive green. The year of implementation is entered into the input box.

3. INPUT DATA PAGES

There are two worksheet pages that require input data and other information. The following describes the required information by worksheet page. In general, cells colored green are for input, and cells colored blue are values passed from the input screen ("schematic2" page).

3.1. INITIAL_CONDITIONS

Initial reservoir storage (for simulation month one) is entered in the green cells for

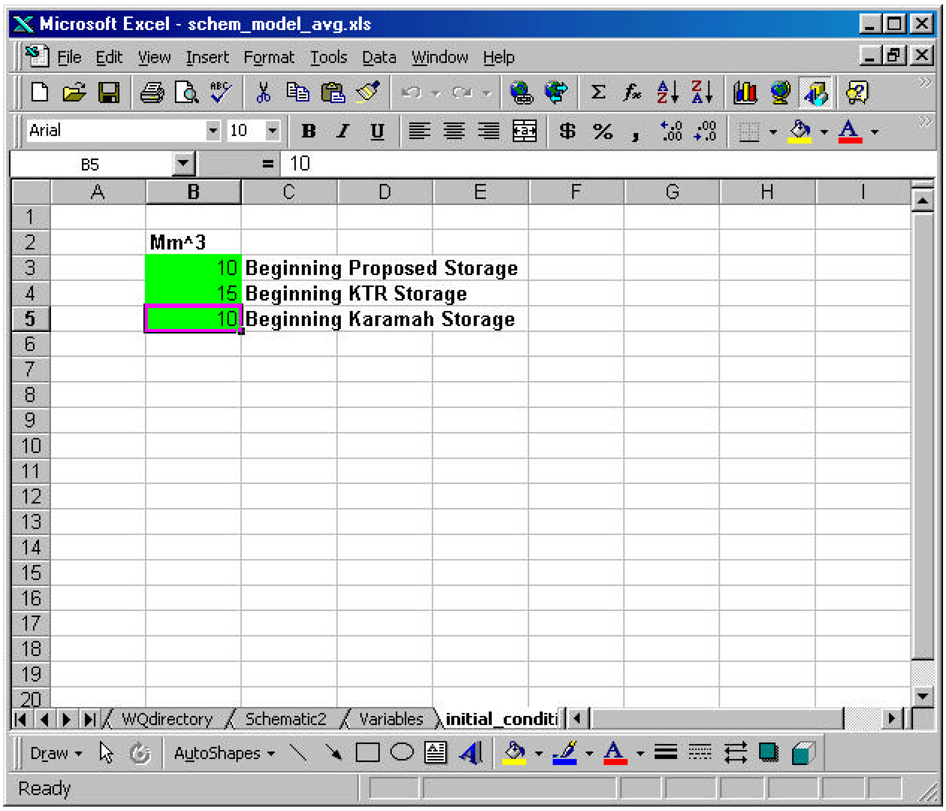


Figure 2. Initial_Conditions Page

KTR, and proposed additional Zarqa Storage. The "initial_ conditions" page is shown in Figure 2.

3.2. VARIABLES

Information for several allocation model components are entered in this page. The section of this page labeled flags, contain flags that are set (TRUE) or cleared (FALSE) based upon the components selected by the user from the model interface page. For example, if the value of pipeline is TRUE, the check box for the KTR bypass pipeline has been selected. The “Variables” page is shown in Figure 3.

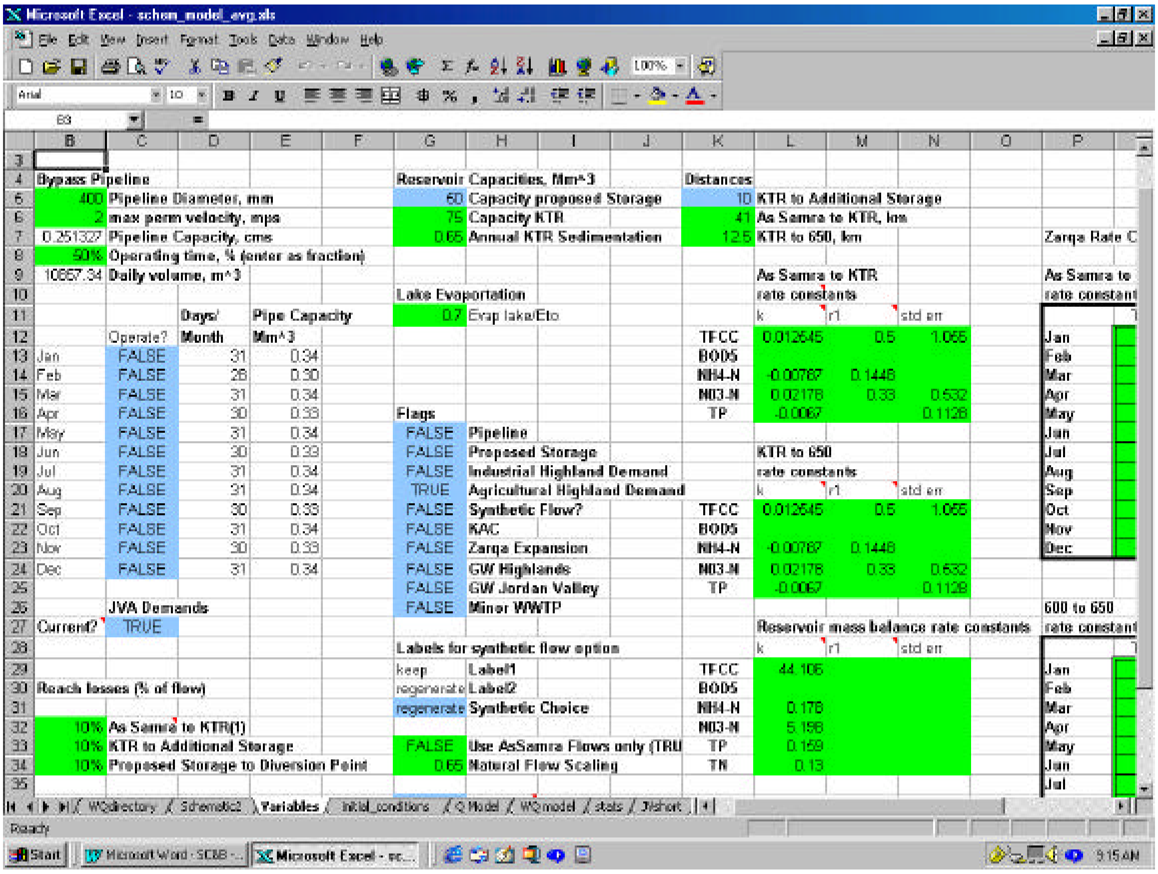


Figure 3. Variables Page showing input variables (green) and those passed from interface (blue) and flags (True/False)

3.2.1. *BYPASS PIPELINE*

The pipeline diameter, in millimeters, the maximum permissible velocity, in meters per second, and the percent of time it is operated per day may are input in the labeled green cells. The daily and monthly volumes are calculated from this information, assuming that average flow velocity in the pipe is the maximum permissible velocity entered. The cells in blue are passed values from the model interface. These should not be changed in this page but rather through the model interface.

3.2.2. *RESERVOIR CAPACITIES*

The capacity for KTR is entered in the appropriately labeled cell. The capacity for the additional storage on the Zarqa is passed from the model interface page.

3.2.3. LAKE EVAPORATION

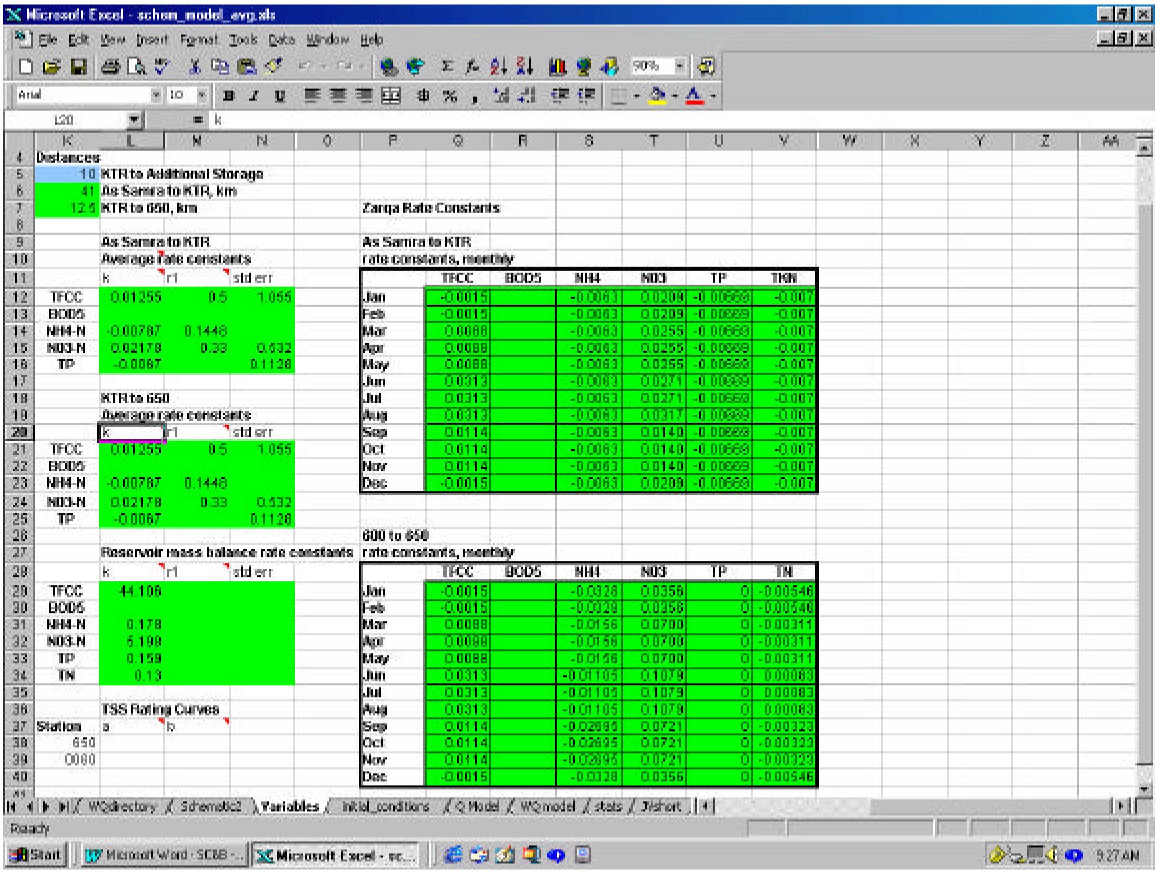
The fraction of reservoir evaporation to reference evapotranspiration, ET_0, is input in the labeled green cell.

3.2.4. DISTANCES

Distances between AsSamra and KTR, and station 600 (KTR outlet) and 650 are entered where labeled. These are fixed distances and need not be changed. The distance from KTR to a proposed storage and from a proposed storage to 650 are calculated from information entered on the schematic page. These distances are used for estimation of certain water quality variables.

3.2.5. ZARQA RATE CONSTANTS

Rate constants must be entered for water quality estimation. These are first order rate constants based on kilometers downstream of the initial concentration rather than time (see tech reference). The constants are from a statistical fit of a first order rate equation. They may vary by season. Constants must be entered for above KTR (AsSamra to KTR) and for downstream of KTR (station 600 to station 650). See Figure 4 for an example.



Distances

10	KTR to Additional Storage
41	As Samra to KTR, km
12.5	KTR to 650, km

As Samra to KTR
Average rate constants

	k	r1	std err
TFCC	0.01255	0.5	1.055
BOD5			
NH4-N	-0.00787	0.1448	
NO3-N	0.02178	0.33	0.532
TP	-0.0067		0.1128

KTR to 650
Average rate constants

	k	r1	std err
TFCC	0.01255	0.5	1.055
BOD5			
NH4-N	-0.00787	0.1448	
NO3-N	0.02178	0.33	0.532
TP	-0.0067		0.1128

Reservoir mass balance rate constants

	k	r1	std err
TFCC	44.106		
BOD5			
NH4-N	0.178		
NO3-N	5.198		
TP	0.159		
TN	0.13		

TSS Rating Curves

Station	a	b
650		
0060		

Zarqa Rate Constants

As Samra to KTR
rate constants, monthly

	TFCC	BOD5	NH4	NO3	TP	TKN
Jan	-0.0015		-0.0063	0.0209	-0.00669	-0.007
Feb	-0.0015		-0.0063	0.0209	-0.00669	-0.007
Mar	0.0088		-0.0063	0.0255	-0.00669	-0.007
Apr	0.0088		-0.0063	0.0255	-0.00669	-0.007
May	0.0088		-0.0063	0.0255	-0.00669	-0.007
Jun	0.0313		-0.0063	0.0271	-0.00669	-0.007
Jul	0.0313		-0.0063	0.0271	-0.00669	-0.007
Aug	0.0313		-0.0063	0.0317	-0.00669	-0.007
Sep	0.0114		-0.0063	0.0140	-0.00669	-0.007
Oct	0.0114		-0.0063	0.0140	-0.00669	-0.007
Nov	0.0114		-0.0063	0.0140	-0.00669	-0.007
Dec	-0.0015		-0.0063	0.0209	-0.00669	-0.007

600 to 650
rate constants, monthly

	TFCC	BOD5	NH4	NO3	TP	TN
Jan	-0.0015		-0.0328	0.0356	0	-0.00546
Feb	-0.0015		-0.0328	0.0356	0	-0.00546
Mar	0.0088		-0.0156	0.0700	0	-0.00311
Apr	0.0088		-0.0156	0.0700	0	-0.00311
May	0.0088		-0.0156	0.0700	0	-0.00311
Jun	0.0313		-0.01105	0.1079	0	0.00083
Jul	0.0313		-0.01105	0.1079	0	0.00083
Aug	0.0313		-0.01105	0.1079	0	0.00083
Sep	0.0114		-0.02695	0.0721	0	-0.00323
Oct	0.0114		-0.02695	0.0721	0	-0.00323
Nov	0.0114		-0.02695	0.0721	0	-0.00323
Dec	-0.0015		-0.0328	0.0356	0	-0.00546

Figure 4. Variables Page (cont.) showing distances and rate constant input cells

3.2.6. RESERVOIR RATE CONSTANTS

These constants are mass balance rate constants for use in modeling outflow water quality from reservoirs. Rates must be entered for each water quality variable (see Figure 4).

3.3. FLOWS

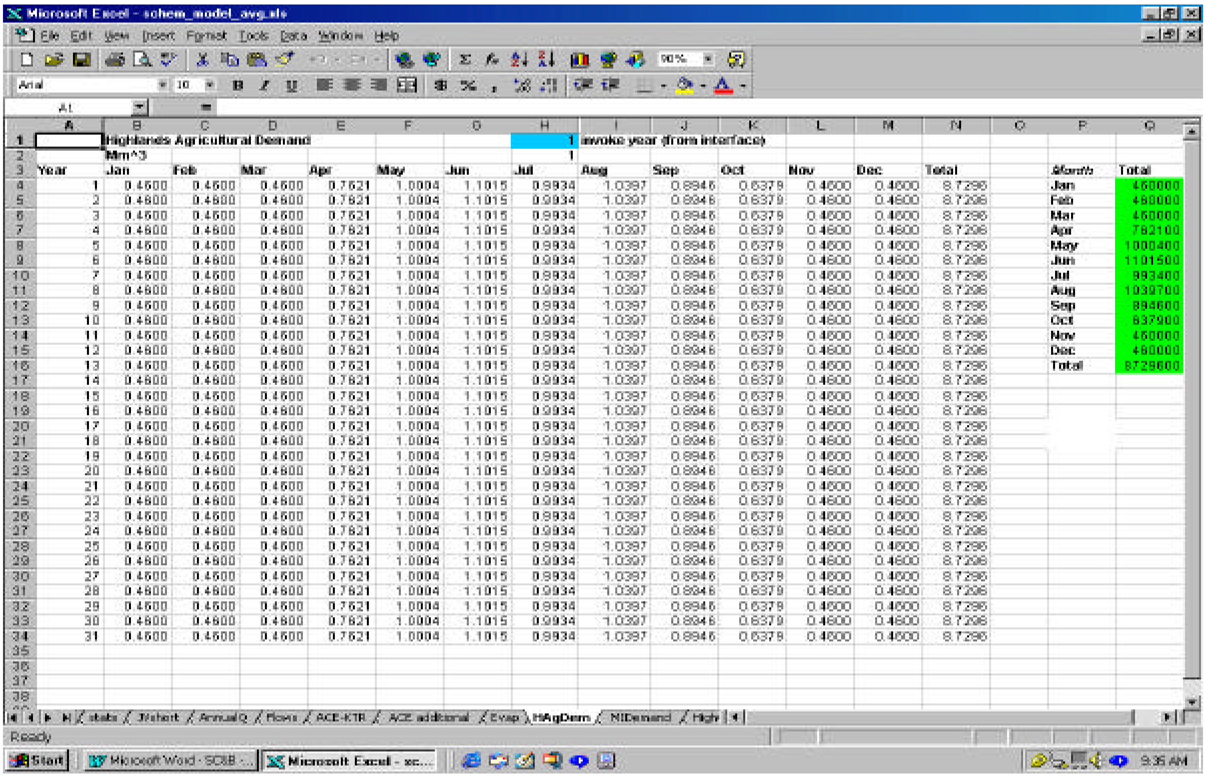
No data entry is required on this page. This page lists flows from AsSamra (effluent), station 0600 (just upstream of KTR) and station 200 (side tributary to KTR). Note that 0600 flows do not include As Samra flows, and are therefore termed “natural flow”. Historic or synthetically generated flows for station 0600 flows in cms are listed depending upon the option selected via the interface "schematic2" page. These flow rates are automatically converted to Mm^3 per month by the program. If synthetic flow is selected, the model accesses another spreadsheet, which generates the flows.

3.4. AREA-CAPACITY-ELEVATION

Area-capacity information for reservoirs is entered in sheet “ACE-KTR” for KTR reservoir and in sheet “ACE additional” for the additional storage on the Zarqa. The flow model accesses these tables to obtain surface area for evaporation calculations.

3.5. DEMAND

There are several spreadsheet pages where demands are entered. These demands comprise agricultural ("HagDem", "ZarqaDem", "WWTP" and "JVA"); municipal and industirial ("MIDemand") and groundwater recharge ("HighGW" and "JVGW"). The page “HAgDem” is typical of the demand pages. Water use by month is entered in the green cells to the right of the year/month water use table. These values should


Microsoft Excel - schem_model_avg.xls

Highlands Agricultural Demand 1 invoke year (from interface)
Mm^3 1

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Month	Total
1	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Jan	460000
2	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Feb	460000
3	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Mar	460000
4	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Apr	762100
5	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	May	1000400
6	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Jun	1101500
7	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Jul	993400
8	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Aug	1039700
9	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Sep	894600
10	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Oct	637900
11	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Nov	460000
12	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Dec	460000
13	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296	Total	8729600
14	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
15	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
16	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
17	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
18	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
19	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
20	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
21	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
22	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
23	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
24	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
25	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
26	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
27	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
28	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
29	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
30	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		
31	0.4600	0.4600	0.4600	0.7621	1.0004	1.1015	0.9934	1.0397	0.8946	0.6379	0.4600	0.4600	8.7296		

Figure 5. Highland Agricultural Demand Page 'HAgDem", showing input cells

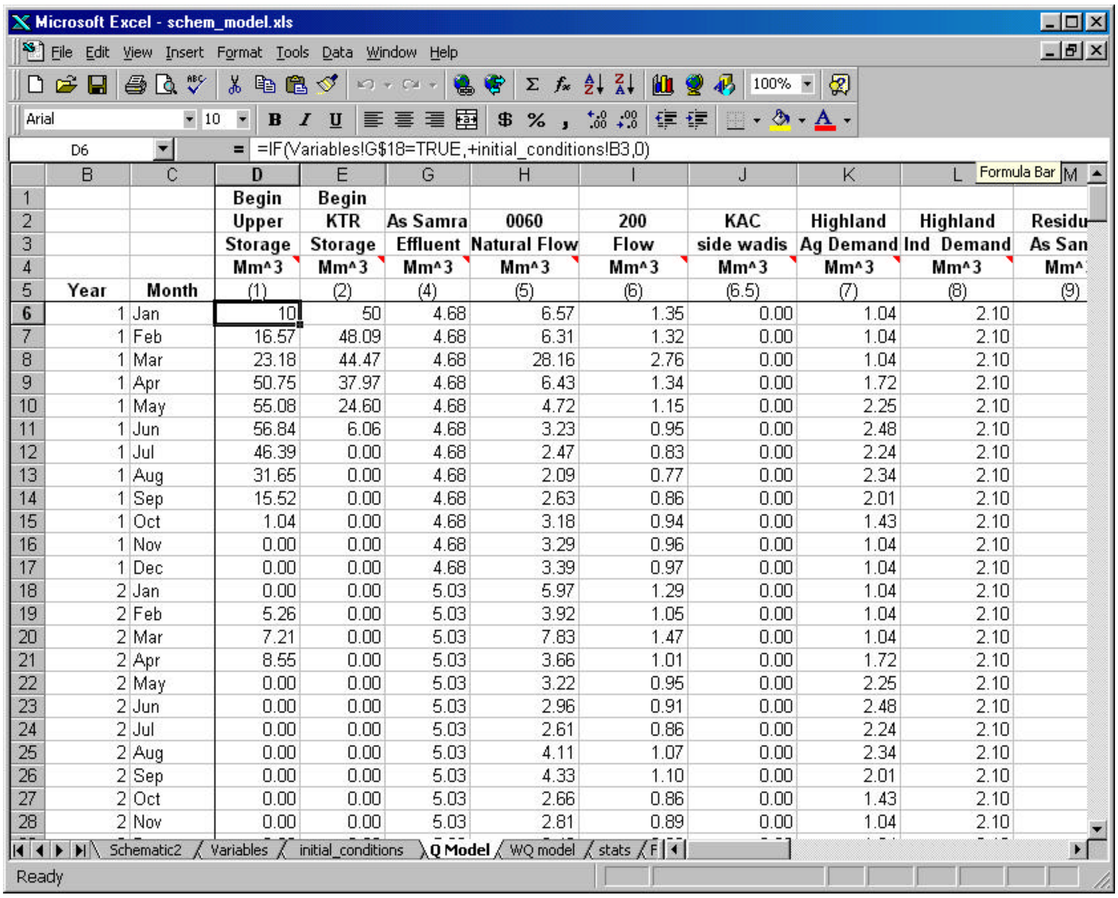
account for conveyance and irrigation efficiency. The simulation year when the demand is begun is entered via the interface on the “schematic2” page. JVA demands are entered by directorate. Figure 5 shows the Highlands Agricultural Demand page.

4. FLOW MODEL

The flow component of the model uses a simple checkbook accounting type method. Water Demands are a debit and inflows are a credit. Reservoirs act as an account which is drafted upon or deposited into. The concept is volume balance:

$$Q_i - D_i + \Delta\,\text{storage} = 0 \qquad (4)$$

where Q_i is inflow into a node (gaging station, reservoir or facility), D_i is demand at that point, and Δstorage is the change in storage (if reservoir considered) from the previous month.


Microsoft Excel - schem_model.xls

D6 =IF(Variables!G$18=TRUE,+initial_conditions!B3,0)

Year	Month	Begin Upper Storage Mm^3 (1)	Begin KTR Storage Mm^3 (2)	As Samra Effluent Mm^3 (4)	0060 Natural Flow Mm^3 (5)	200 Flow Mm^3 (6)	KAC side wadis Mm^3 (6.5)	Highland Ag Demand Mm^3 (7)	Highland Ind Demand Mm^3 (8)	Residu As San Mm^ (9)
1	Jan	10	50	4.68	6.57	1.35	0.00	1.04	2.10	
1	Feb	16.57	48.09	4.68	6.31	1.32	0.00	1.04	2.10	
1	Mar	23.18	44.47	4.68	28.16	2.76	0.00	1.04	2.10	
1	Apr	50.75	37.97	4.68	6.43	1.34	0.00	1.72	2.10	
1	May	55.08	24.60	4.68	4.72	1.15	0.00	2.25	2.10	
1	Jun	56.84	6.06	4.68	3.23	0.95	0.00	2.48	2.10	
1	Jul	46.39	0.00	4.68	2.47	0.83	0.00	2.24	2.10	
1	Aug	31.65	0.00	4.68	2.09	0.77	0.00	2.34	2.10	
1	Sep	15.52	0.00	4.68	2.63	0.86	0.00	2.01	2.10	
1	Oct	1.04	0.00	4.68	3.18	0.94	0.00	1.43	2.10	
1	Nov	0.00	0.00	4.68	3.29	0.96	0.00	1.04	2.10	
1	Dec	0.00	0.00	4.68	3.39	0.97	0.00	1.04	2.10	
2	Jan	0.00	0.00	5.03	5.97	1.29	0.00	1.04	2.10	
2	Feb	5.26	0.00	5.03	3.92	1.05	0.00	1.04	2.10	
2	Mar	7.21	0.00	5.03	7.83	1.47	0.00	1.04	2.10	
2	Apr	8.55	0.00	5.03	3.66	1.01	0.00	1.72	2.10	
2	May	0.00	0.00	5.03	3.22	0.95	0.00	2.25	2.10	
2	Jun	0.00	0.00	5.03	2.96	0.91	0.00	2.48	2.10	
2	Jul	0.00	0.00	5.03	2.61	0.86	0.00	2.24	2.10	
2	Aug	0.00	0.00	5.03	4.11	1.07	0.00	2.34	2.10	
2	Sep	0.00	0.00	5.03	4.33	1.10	0.00	2.01	2.10	
2	Oct	0.00	0.00	5.03	2.66	0.86	0.00	1.43	2.10	
2	Nov	0.00	0.00	5.03	2.81	0.89	0.00	1.04	2.10	

Schematic2 / Variables / initial_conditions / Q Model / WQ model / stats

Figure 6. "QModel" page

The volume balance or checkbook model is implemented in page “Qmodel”. The flow of logic is from left to right, with beginning of month storages at the left side of the sheet, followed by flows. Demands are then imposed upon the flows and storages, and end of month storage values are calculated. Each column has a note which shows and explains the calculation in that column. The cells with notes are identified by small red triangles in the cell. The layout of the page is shown in Figure 6.

As Samra flows are first used to satisfy highland demands, then the residual is added to Zarqa natural flows for use along the Zarqa or for placement into storage downstream. When allocating water into storage, the model first seeks to satisfy Jordan Valley Authority (JVA) demands by using residual AsSamra flows from the bypass pipeline if selected, then by water stored in a proposed storage (if it exists) which is located downstream of KTR. It then looks to storage in KTR to satisfy any residual demand. Pipeline diversions are limited by pipeline capacity and the operation schedule input via the interface ("schematic2" page).

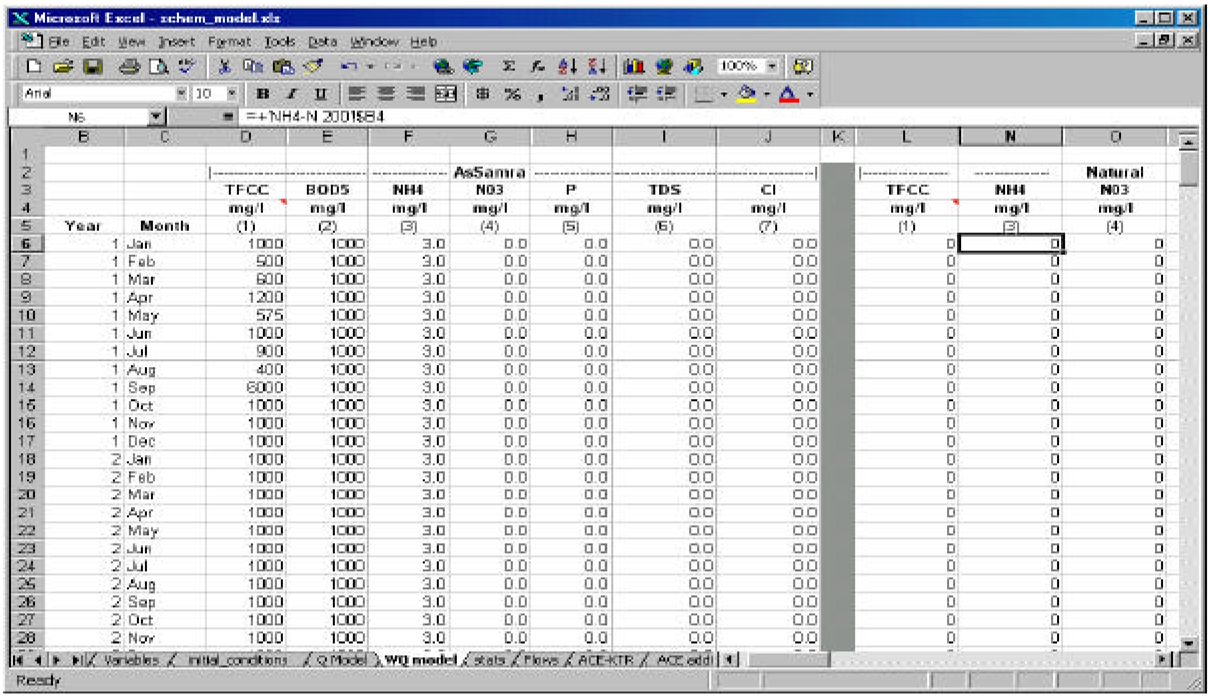
An initial calculation of end of month storage is averaged with the beginning of month storage to obtain an average monthly volume. Surface area is calculated from volume and an estimate of reservoir evaporation is obtained. Evaporation is then subtracted from the initial end of month storage estimate to obtain a refined value of end of month storage.

5. WATER QUALITY MODEL

The water quality component uses flows from the flow model, along with initial conditions of water quality at AsSamra and water quality for Zarqa natural flow to estimate water quality at selected points. Empirically fit rate equations are used for transforming constituents such as fecal coliform, NH_4-N, NO_3-N, and TP, while conservative constituents such as TDS and chloride are modeled by mass balance, simply flow-weighting the blended flows of differing water quality.

Input data consists of monthly water quality data at AsSamra. Each water quality variable modeled has a page for AsSamra input data. Concentration of conservative constituents (Chloride and TDS) for natural flow is estimated by correlation to streamflow with existing data. Nitrate and total phosphorus are also estimated from a correlation to flow for Station 200 only.

The model predicts water quality downstream of AsSamra using first-order rate equations for transforming/decaying constituents and mass balance for conservative constituents. This



	B	C	D	E	F	G	H	I	J	K	L	N	O
1													
2			AsSamra										Natural
3			TFCC	BOD5	NH4	NO3	P	TDS	Cl		TFCC	NH4	NO3
4			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l		mg/l	mg/l	mg/l
5	Year	Month	(1)	(2)	(3)	(4)	(5)	(6)	(7)		(1)	(3)	(4)
6	1	Jan	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
7	1	Feb	900	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
8	1	Mar	600	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
9	1	Apr	1200	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
10	1	May	575	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
11	1	Jun	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
12	1	Jul	900	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
13	1	Aug	400	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
14	1	Sep	6000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
15	1	Oct	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
16	1	Nov	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
17	1	Dec	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
18	2	Jan	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
19	2	Feb	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
20	2	Mar	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
21	2	Apr	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
22	2	May	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
23	2	Jun	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
24	2	Jul	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
25	2	Aug	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
26	2	Sep	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
27	2	Oct	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0
28	2	Nov	1000	1000	3.0	0.0	0.0	0.0	0.0		0	0	0

Figure 7. WQ Model page

process proceeds in a downstream sequence. The water quality model is contained in the page "WQ Model" which access required information from various other pages. The layout of the water quality model page is shown in Figure 7.

6. OUTPUT

Output from the spreadsheet model consists of graphs and summary statistics.

6.1. GRAPHS

Graphs are activated by clicking on the desired gaging or water quality station on the schematic page. The graphs are placed on a workbook page (worksheet) and thus may also be accessed by selecting the appropriate page. Gaging station graphs show monthly flows or end of month storage for stream or reservoir stations respectively. Water quality stations show concentration of variables over time. Graphs are automatically regenerated as input is changed. The user can return to the schematic page by clicking on the "return to schematic" button. An example graph is shown in Figure 8.

In addition, graphs showing predicted concentration of individual water quality variables in inflow and outflow of KTR, the proposed additional storage and at Station 650 may be viewed. These are accessed by clicking on the "for more details on water quality" button on the "schematic2" page, then selecting the desired station and variable.

6.2. SUMMARY STATISTICS

Summary statistics for annual supply (flows) and annual demands (JVA and highlands) are generated automatically. They can be accessed from the user interface by clicking the “summary statistics” button. Example statistics are shown in Figure 9.

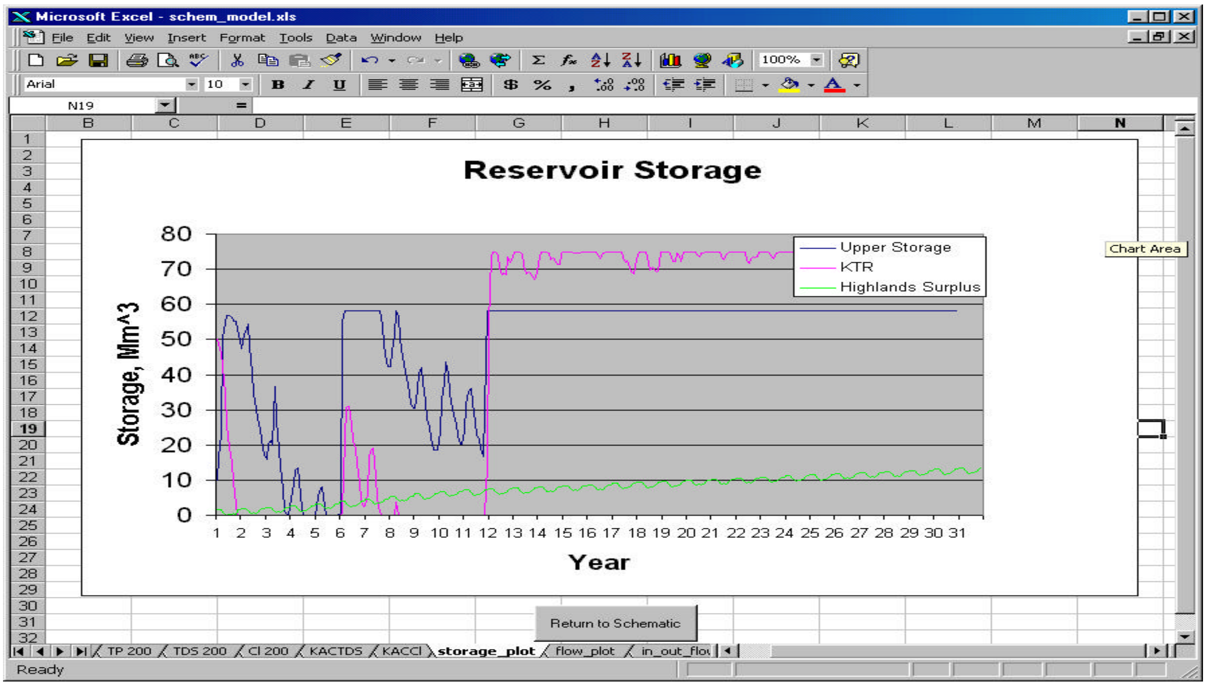


Figure 8. End of month storage plot

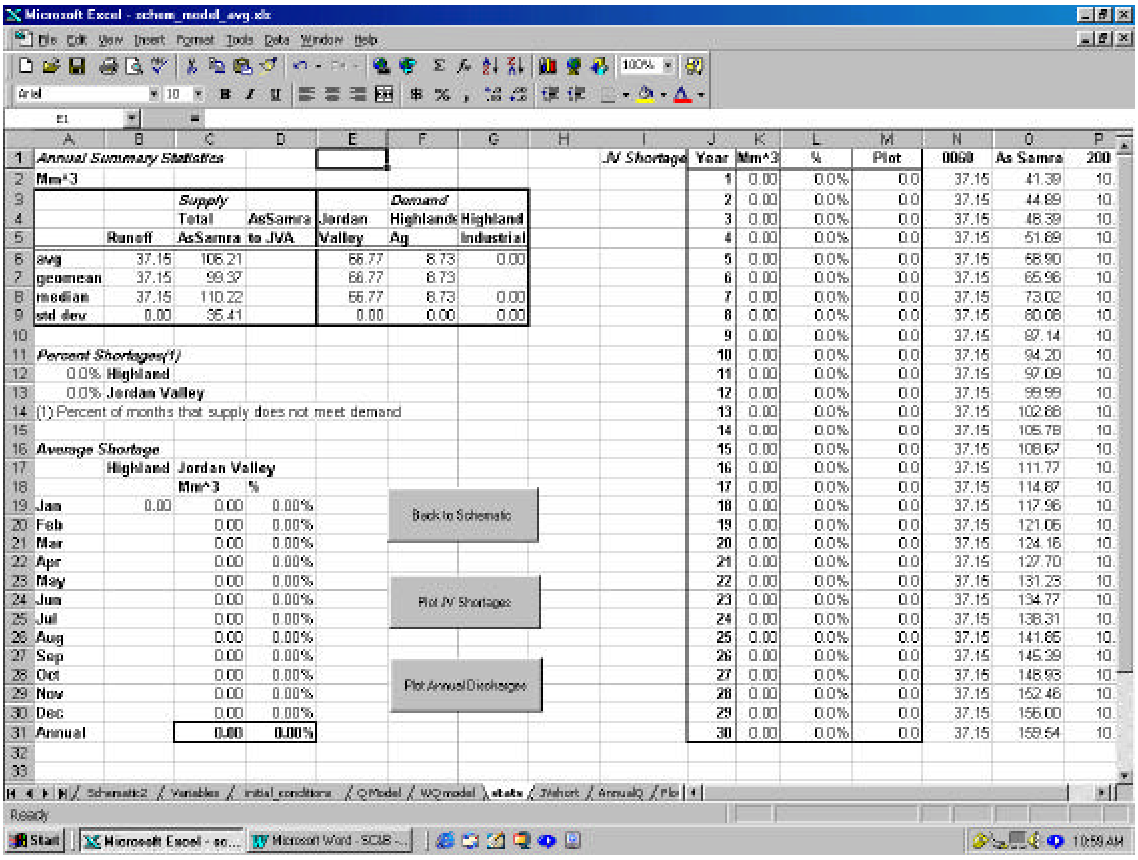


Figure 9. Statistics page

APPENDIX C
WATER QUALITY SAMPLING & REDUCTION

This memo is intended to bring to attention the impact of water quality sampling strategy, and data reduction in obtaining the best estimate of water quality and salt or nutrient loads, or detect a change in the concentrations or loads.

Sampling strategy

Sherwani and Moreau (1975) state that the desired frequency of sampling is a function of several considerations associated with the system to be studied, including:

- Response time of the system;
- Expected variability of the parameter;
- Half-life and response time of constituents;
- Seasonal fluctuation and random effects;
- Representativeness under different conditions of flow;
- Short-term pollution events;
- Magnitude of response; and
- Variability of the inputs.

Sampling strategy (when and how frequent) should be based upon the water quality variable of concern. Some variables are highly flow dependent and therefore benefit from sampling not only during low flow periods but high flow periods.

Even Interval

Probably the most common type of water quality sampling is even interval. As the label implies, sampling is done at an even or fixed interval, normally weekly, biweekly, or monthly. If trends in water quality are present within a weekly period, e.g., a discharge from a point source on a certain day, the sampling can be improved by shifting the interval such that all days are sampled. Oftentimes, even interval strategies miss storm event flows, and therefore are weak in obtaining concentration data, and especially weak in obtaining load data.

Event based

Event based data is preferable when an estimation of loads are desired. Sampling occurs during periods of high flow, which is the period when most of the load is transported. The easiest way to obtain event-based samples is to use an automated sampler (Isco, etc), which is triggered to activate when a certain stage is reached. Samples are collected either at even intervals (time weighted) or when a predetermined amount of flow passes (flow weighted).

Spatial correlation

If correlation of water quality variables at different water quality sampling stations is to be made sampling should be done within a reasonable time scale, such that hydrologic conditions are approximately the same.

Load Concept

The load of a pollutant, whether it be sediment, or a nutrient, such as Nitrogen or Phosphorus, is obtained by integration the flux of the pollutant over a given time period.

$$Load = \int_t flux(t)dt \qquad \text{(C-5)}$$

where load is the mass of pollutant passing a point over a given period of time (*dt*) normally expressed in kilograms, and flux is the instantaneous mass rate of discharge passing a point, normally expressed in kilograms per unit time.

The flux is the mass rate of discharge, such as kg per second or kg per hour. Flux is normally obtained by multiplying concentration by water discharge and applying any appropriate conversions. The concept of flux and load is illustrated in Figure C-1. The three methods of estimating pollutant load discussed below attempt to estimate the actual load with flow and concentration data collected from sampling programs.

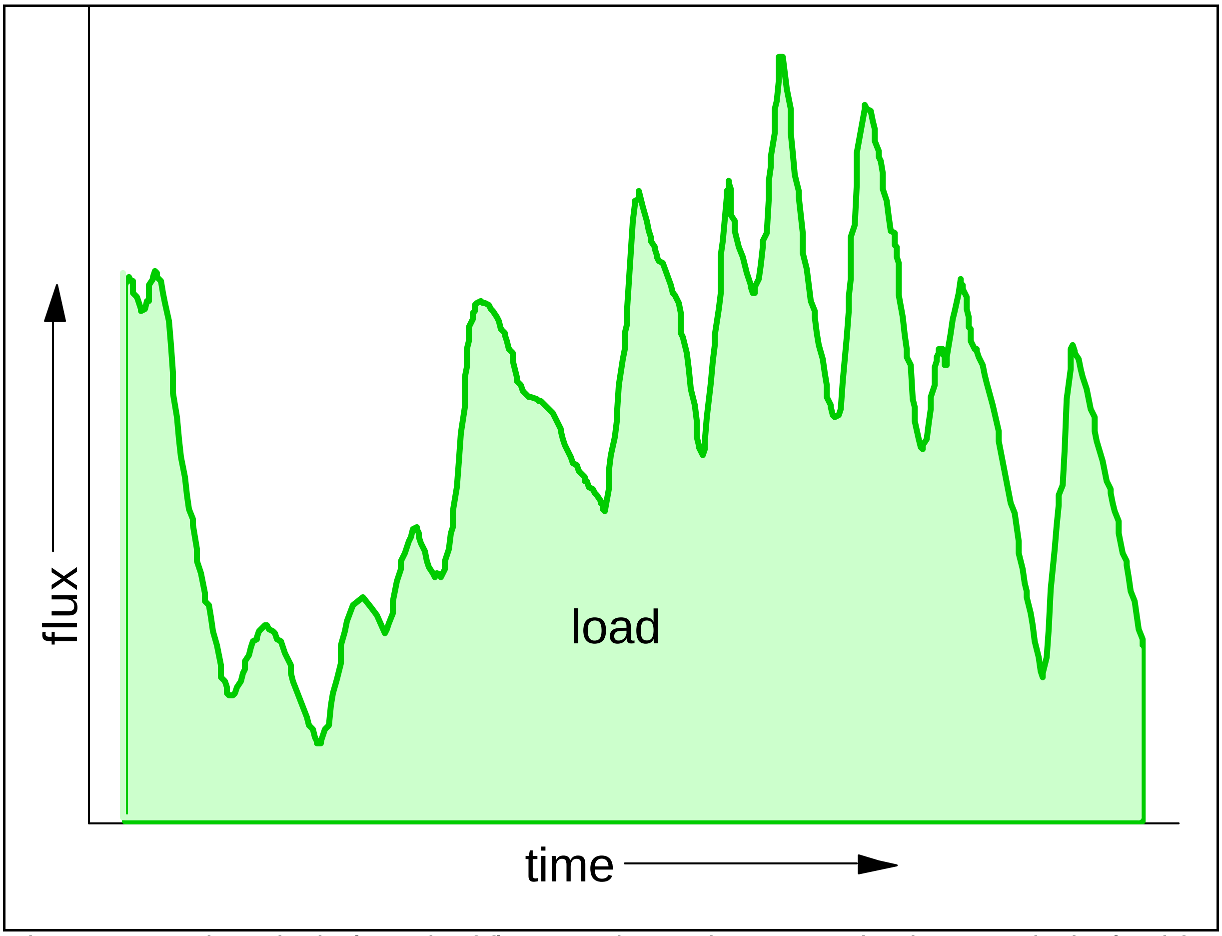


Figure C-1. A hypothetical graph of flux over time. The area under the curve is the load for the time interval (from Richards, 1999).

Data reduction and Load Calculation

There are essentially three ways to estimate loads (either salt or nutrient) from water quality sample data; integration, regression, or ratio estimators.

Integration Method

Integration is the most intuitive way, and simply sums up discrete products of flow time concentration. This method is given in EPA (1999), and Richards (1999). The integration method simply estimates the continuous function presented in Equation C-1 and Figure C-1 by summing the product of discrete measurements and time intervals

$$Load = k\sum_{i=1}^{n} c_i q_i \Delta t \qquad \text{(C-6)}$$

As the time intervals between measurements increase, the estimate of load by this method normally becomes less accurate.

Sampling Stategy

This sampling strategy for the integration method assumes that most load occurs during storm events, and that flow rates and concentrations during storm events change "smoothly" over time. Accordingly, sampling should be biased toward storm events and done frequently enough to insure that large rates of change in either flow or concentration do not occur between samples.

Regression Method

he regression method takes advantage of correlation of water quality to streamflow, and the fact that streamflow is sampled more often (oftentimes continuously) than water quality. The simplest form of this method is to estimate water quality for the chosen time step (or at the frequency of flow data) then multiply this estimated concentration by discharge to get mass for the time step. With this method regression analysis is normally done on concentration versus discharge:

$$\hat{c} = m\overline{q} + b \qquad \text{(C-7)}$$

where $\hat{c}$ is the predicted concentration and $\bar{q}$ is the average discharge over the time period for which concentration is estimated. This relationship is then used to estimate concentration when concentration data does not exist. The load for the desired time period is then calculated by:

$$Load = k\sum_{i=1}^{n} \hat{c}_i \overline{q}_i \qquad \text{(C-8)}$$

where $\hat{c}$ is taken from Equation (C-3), q is the average flow for the time period, and k is a unit conversion factor. If an annual load is desired, then n would be 365, and $\bar{q}$ would be average daily discharge.

There are other regression methods that use other factors in addition to streamflow as in the USGS ESTIMATOR program (USGS, 1992) and the methods presented by the U.S. Army Corps of Engineers (1996) in their FLUX program.

Sampling Stategy

Since the object of regression methods is to characterize the impact of flow on concentration, enough samples must be taken a the appropriate time to develop the relationship in Equation (C-3). Cohn *et al.* (1992) used 75 samples to establish their regression models. In establishing the regression relationship, it is important that a number of flow-concentration samples be collected during high flow periods. For most constituents or pollutants, most of the load will be transported during high flow periods.

Ratio Methods

The third method of estimating loads is by using ratio methods (Beale, 1962; Cochran, 1977). Like regression methods, ratio estimators are designed to combine infrequent concentration measurements with frequent flow measurements. This method operates with a ratio of known loads and known discharge and adjusts that with recorded discharges for those days (or time intervals) that concentration is not measured.

Sampling Stategy

Ratio estimators assume random sampling and assume a normal distribution. The number of samples required to be within a certain deviation of the mean daily load (assuming daily load estimates) is given by Equation C-5.

$$n = \frac{t^2 s^2}{E^2} \qquad \text{(C-9)}$$

where n is the number of random samples required to be within a certain error, E, s^2 is the variance estimate of the load, and t is the t value for the desired confidence level of the error, E, occuring. This equation is for use with a non-stratified sampling program, or in other words, one that samples randomly over the entire flow period, rather than sampling separately within low flow and high flow periods. For stratified random sampling, a two-step procedure is required (Darnell, 1977).

Number of samples

More samples yields a better estimate of the mean concentration and a better idea of the flux or load over a period of time. If the standard deviation of the concentration is known, the number of samples required for the estimate to be within a given error of the mean is:

$$n = \frac{t^2 s^2}{d^2} \qquad \text{(C-10)}$$

Where n in number of samples required, s is the standard deviation, t is from a t-distribution selected for the desired confidence level and d is the error margin (Sanders, et al, 1990).

If management practices are anticipated for a river basin, the amount of change in concentration or load required to detect that change is termed the minimum detectable change. This level of required change can be obtained by rearranging the above equation to solve for d. In this case s^2 is the pooled variance, based upon the before and after standard deviations and respective number of samples taken before and after the management change.

Zarqa River Application

The number and location of water quality sampling stations appears to be sufficient for the objectives in the water reuse portion of the policy support project. Some comments on sampling strategy and implications follow.

The Zarqa River is an event response river (Yaksich, et al, 1983), in that concentrations change with flow. For station 200, TDS, Cl-, NO3- and TP all decrease in concentration with increasing discharge. The decrease in TP is not expected as normally total suspended sediment (TSS) increases with increasing discharge, and normally TP follows due to P typically being attached to sediment. The correlation between TSS and discharge at station 650 was investigated and no correlation was found. One of the problems is that sampling is done primarily at low flow, so it is difficult to ascertain a relationship of TSS with discharge. Exclusive low flow sampling may be the reason that a negative correlation was found between TP and discharge. (Including samples at higher discharges may have proven a positive correlation).

Since the Zarqa is an event response river, calculation of salt or nutrient loads requires sampling at high flows. Intensive sampling of just 3 to 4 storm events per year would allow for much improved information of concentration response to higher discharge and therefore an improved estimate of loads. Consideration should be given to a sampling program that includes automated samplers designed to sample at higher flows. Guidance for programming an automated sampler is given below as taken from (Richards, 1999):

> *To determine the sampling interval during storm runoff events, divide the length of a runoff event by 16. The result may be rounded somewhat for convenience. For example, a sampling interval of 7.3 hours can be rounded to 8 hours.*
>
> *To determine when sampling should start, do one of the following:*
>
> *1. By inspection of existing records of stage, determine a stage which separates early storm runoff from base flow, and program the autosampler to begin when this stage is exceeded. Different triggering stages may be appropriate in different seasons.*
>
> *2. By inspection of existing records of stage, determine a rate of change of stage which characterizes the onset of storm runoff. Program the autosampler to begin when this rate of change is exceeded.*
>
> *To determine when sampling should stop, do one of the following:*
>
> *1. Trigger the autosampler to stop sampling, or turn it off manually, when the stage decreases to less than 110% of the stage at which sampling started.*
>
> *2. Turn off the autosampler manually when the water level and turbidity indicate that storm runoff has ceased, but not before 16 samples have been obtained.*
>
> *2. Allow the autosampler to complete its cycle of sampling (typically 24 samples), at which time it will stop sampling automatically.*
>
> *In addition to storm sampling, take one sample during low flow conditions during each month.*
>
> *Stages must be recorded at hourly intervals for rivers for which a typical storm lasts four days or more, at 15 minute intervals for rivers with storm durations between one and four days, and at 5 minute intervals for rivers with storm durations less than one day. These stages must be converted to flows for use in calculating the loads, using an established and verified rating curve.*

If any change in water quality is to be detected on the Zarqa River, a combination of a better sampling campaign with fairly dramatic reductions in concentrations will be required. It is not unusual for a minimum detectable change for total phosphorus load be 50% or higher. It is rare to have a minimum detectable change of less than 20% for any water quality variable, unless the variable is relatively constant and/or a large number of samples are planned. Monitoring storm events can greatly reduce the amount of change required to be statistically detected (Line, et al, 1998).

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APPENDIX D
PRELIMINARY (SCENARIO GROUPS A&B) AND MODEL OUTPUT

The two basic scenarios considered were:

A. maximizing replacement of existing freshwater uses and meeting new demands in the highlands; and
B. maximizing benefit/cost of water reuse.

Each of these scenarios is presented below in terms of the priority of the water reuse options. It is assumed that existing uses of reclaimed water in the Amman-Zarqa basin and Jordan Valley have a prior right to the resource. Variations in sequencing particular options within each scenario were also examined.

D.1.1. Scenario A

This scenario assumes aggressive development to replace, either directly or indirectly, existing uses of fresh water supply and meet new demands that would otherwise use freshwater resources. The basic scenario, in terms of priority of options, were as follows:

10) Hashemite-Zarqa-Ruseifeh (HZR) Industrial/Municipal Water Reuse
11) Groundwater Recharge in the Highlands[1]
12) Wadi Dhuleil Irrigation Project (HL#3)
13) Minor Wastewater Treatment Plant Options
14) Groundwater Recharge in the Jordan Valley[1]
15) Wadi Zarqa Intensification
16) Middle Directorate Intensification
17) Karameh Directorate Intensification
18) Northern Directorate Replacement

[1]*Assumes groundwater recharge proves feasible.*
[2]*Initially at low priority but will be examined separately.*

D.1.2. Scenario B

The scenario prioritizes options based on maximizing the benefit cost ratio. The final prioritization is likely to adjust as more details on benefits and costs are generated. The basic scenario, in terms of priority of options, is as follows:

1) Middle Directorate Intensification
2) Karameh Directorate Intensification
3) Wadi Zarqa Intensification
4) Groundwater Recharge in the Highlands[1]
5) Minor Wastewater Treatment Plant Options
6) Hashemite-Zarqa-Ruseifeh (HZR) Industrial/Municipal Water Reuse
7) Wadi Dhuleil Irrigation Project (HL#3)
8) Groundwater Recharge in the Jordan Valley[1]

9) Northern Directorate Replacement

[1]*Assumes groundwater recharge proves feasible.*
[2]*Initially at low priority but will be examined separately*

D.2. VARIATIONS OF BASIC SCENARIOS

In addition to the basic scenarios present above, there are a number of variations to be considered including supplying reclaimed water to the Northern Directorate as a priority, removal of the groundwater recharge options, and the removal of water reuse option at the minor wastewater treatment plants. This matrix of scenarios is presented in Appendix D.1. Also, the priority of each option for each scenario considered is presented in Table D.2.

Table D.1. Scenarios for water reuse

SCENARIO	A	B
Basic	A(1)	B(1)
Prioritize Northern Directorate	A(2)	B(2)
No Groundwater Recharge	A(3)	B(3)
No Reuse at Minor WWTPs	A(4)	B(4)

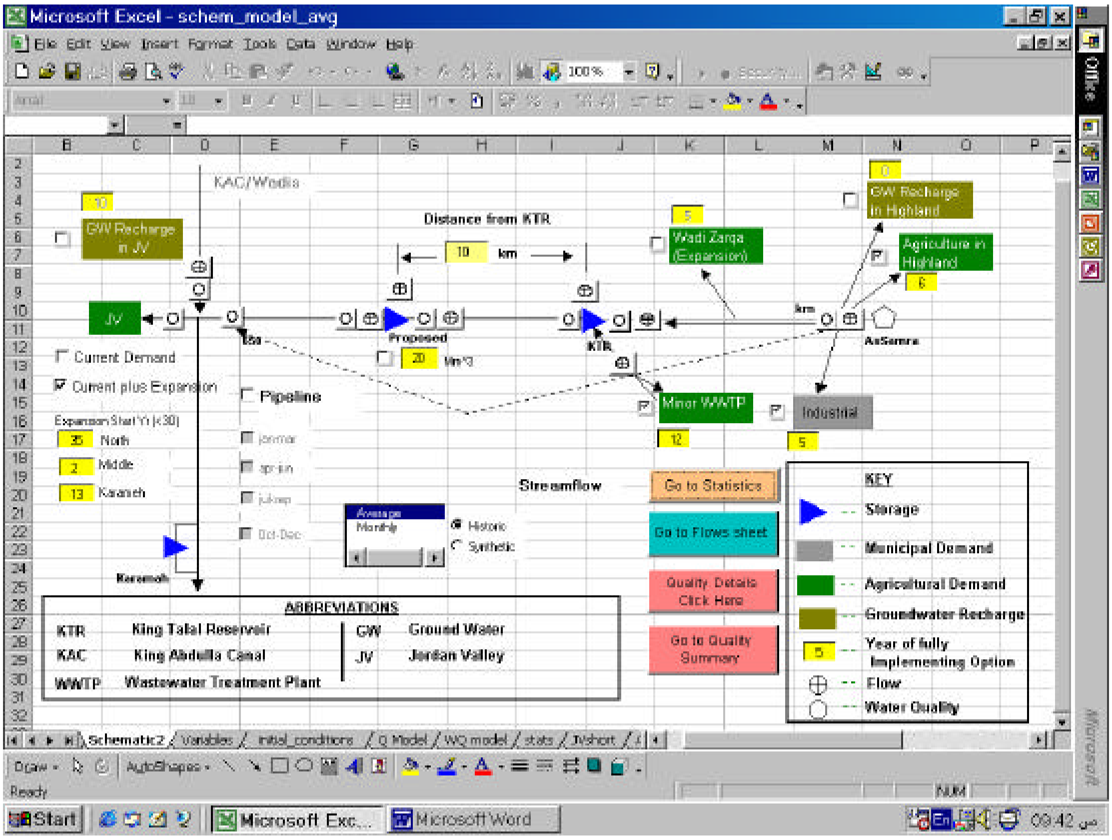
Table D.2. Prioritization of options for each basic scenario

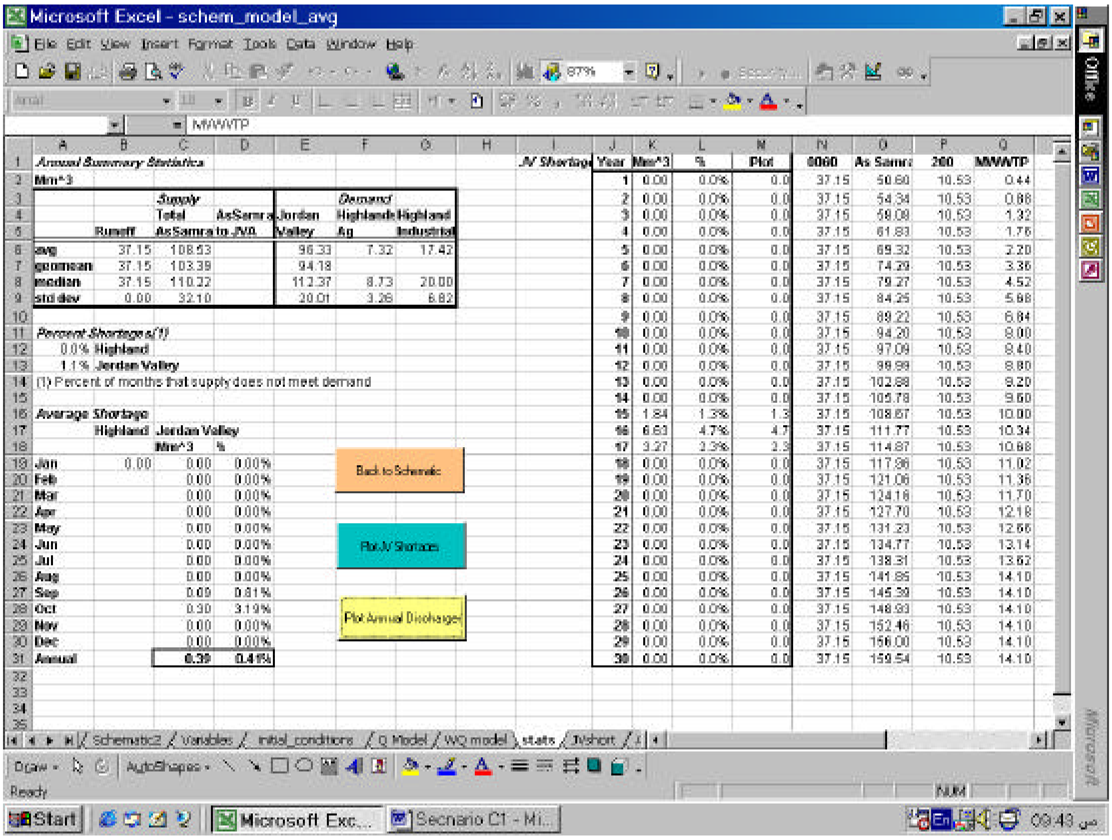
	OPTIONS											
	Wadi Dhuleil Irrigation Project (HL#3)	**HZR Industrial Municipal**	**Wadi Zarqa**		**Middle Directorate**		**Karameh Directorate**		**Northern Directorate**	**Minor WWTP Reuse**	**Groundwater Recharge**	
SCENARIO			**Existing (17 K-dnms)**	**Intensification (3 K-dnms)**	**Existing**	**Intensification**	**Existing**	**Intensification SO#6, 9 & 10**			**Highlands**	**JV**
A(1)	3	1	0	6	0	7	0	9		4	2	5
A(2)	4	2	0	7	0	8	0	9	1	5	3	6
A(3)	2	1	0	4	0	5	0	6		3		
A(4)	3	1	0	5	0	6	0	7			2	4
B(1)	7	6	0	3	0	1	0	2		5	8	4
B(2)	8	7	0	4	0	2	0	3	1	6	9	5
B(3)	6	5	0	3	0	1	0	2		4		
B(4)	6	5	0	3	0	1	0	2			7	4

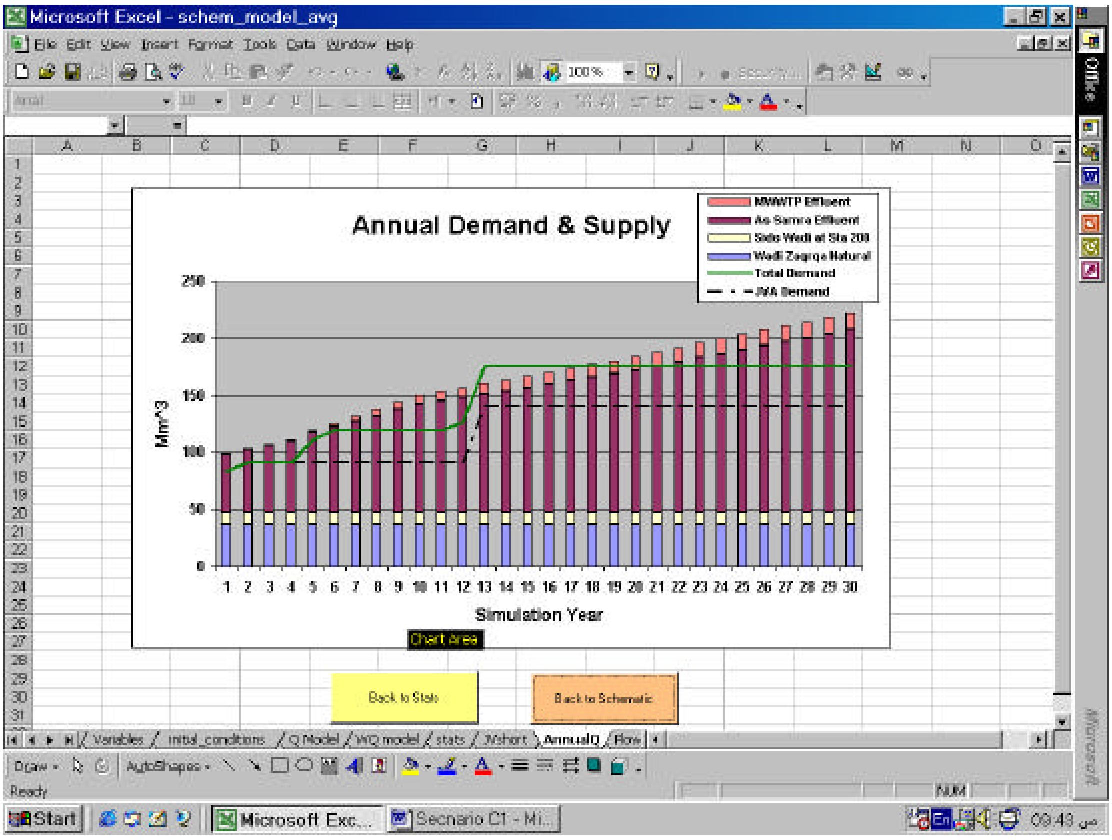
1-9 – Priority of option in the scenario with “1” being highest priority.
0 – Existing users of reclaimed water given highest priority in all scenarios.

APPENDIX E
WORKING SCENARIOS (SCENARIO GROUP C) MODEL OUTPUT

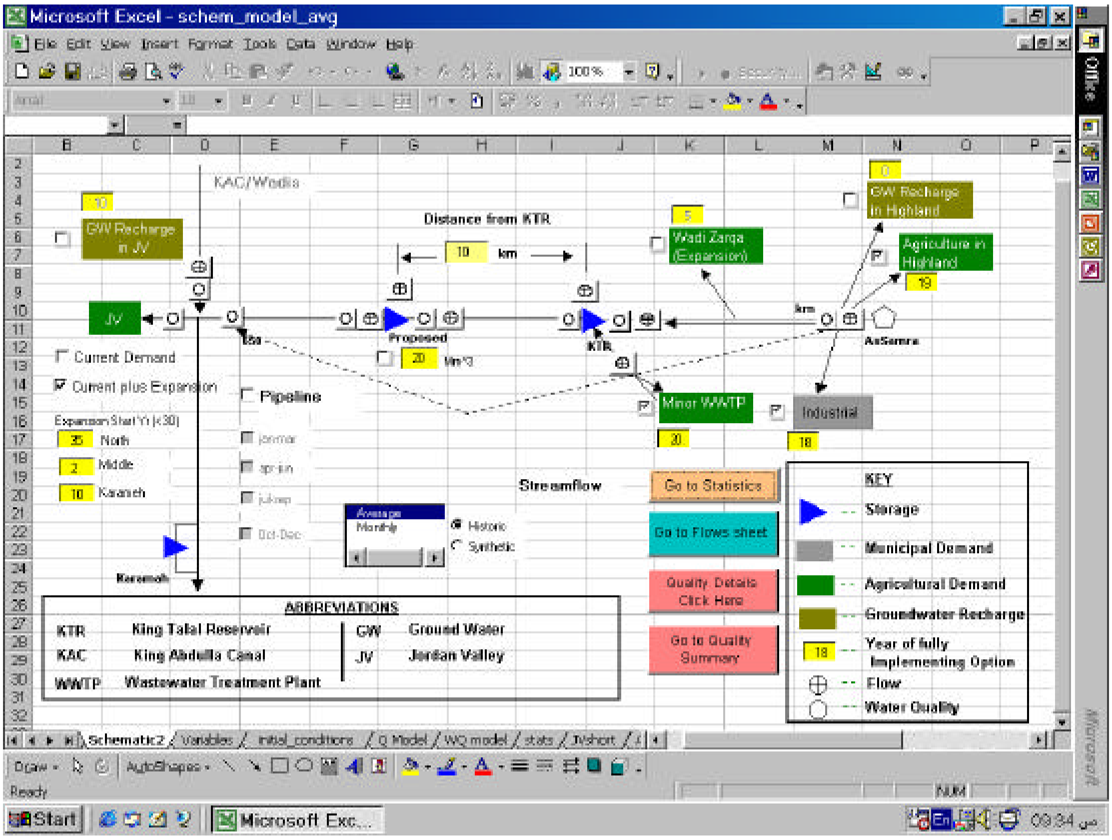
Output from Scenario C1

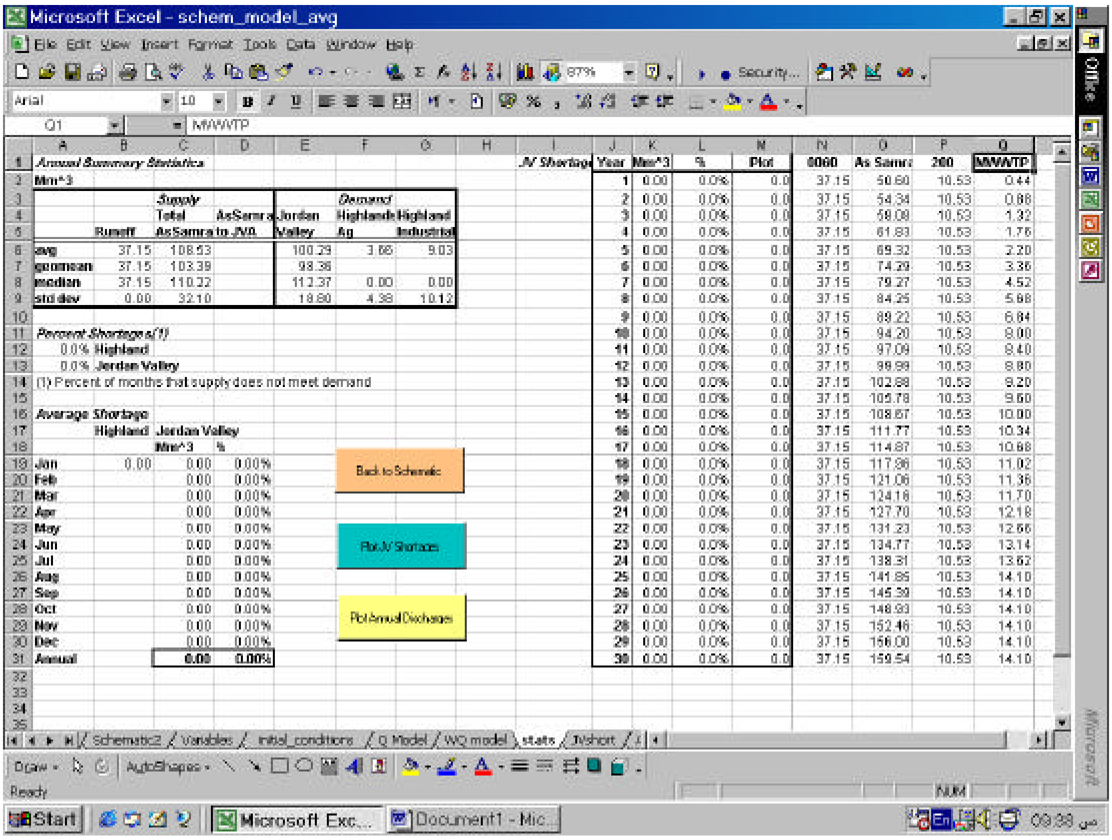


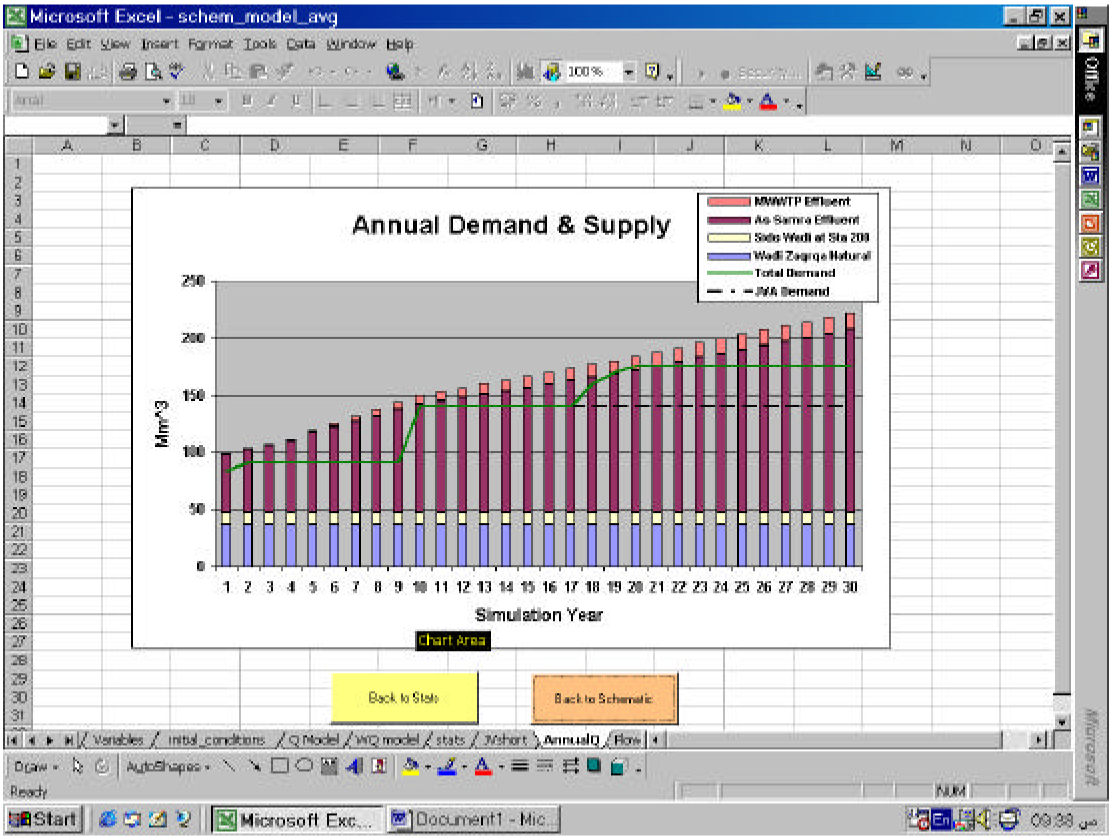



Annual Demand & Supply
MWWTP Effluent
As Samra Effluent
Sids Wadi at Sta 200
Wadi Zagrqa Natural
Total Demand
JVA Demand
Mm^3
Simulation Year
Back to Stats
Back to Schematic

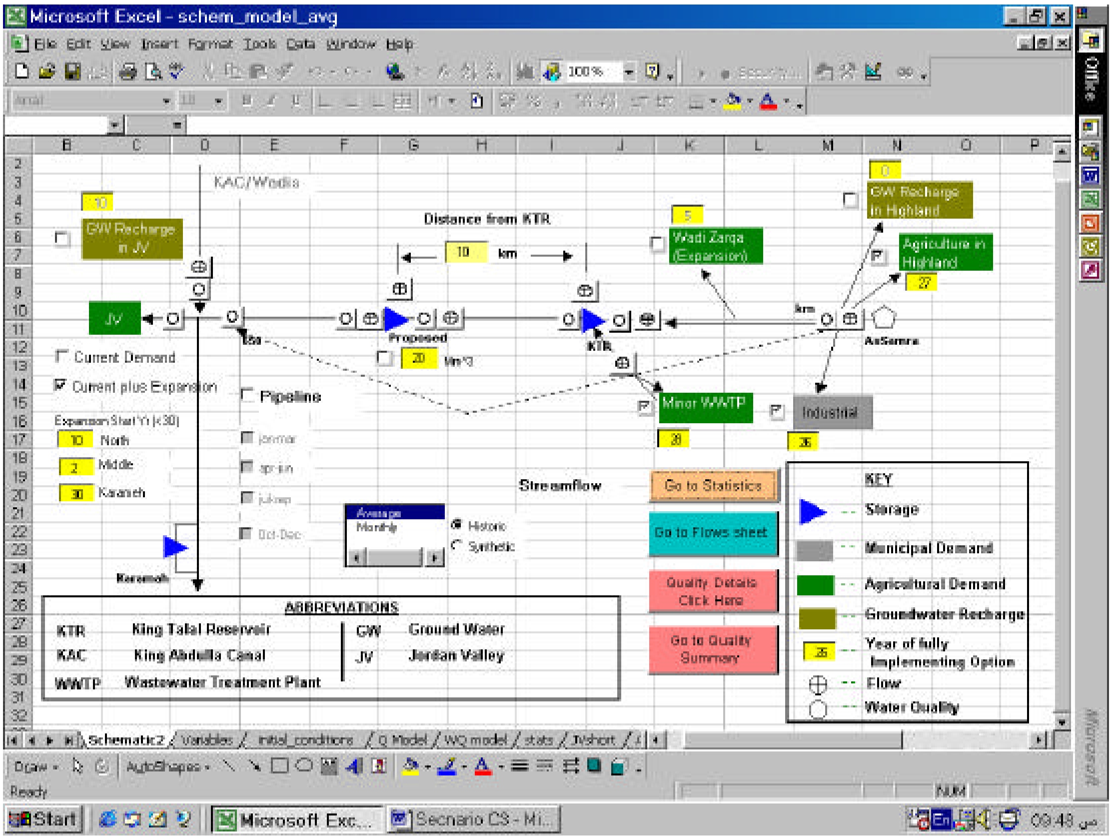
Output from Scenario C2

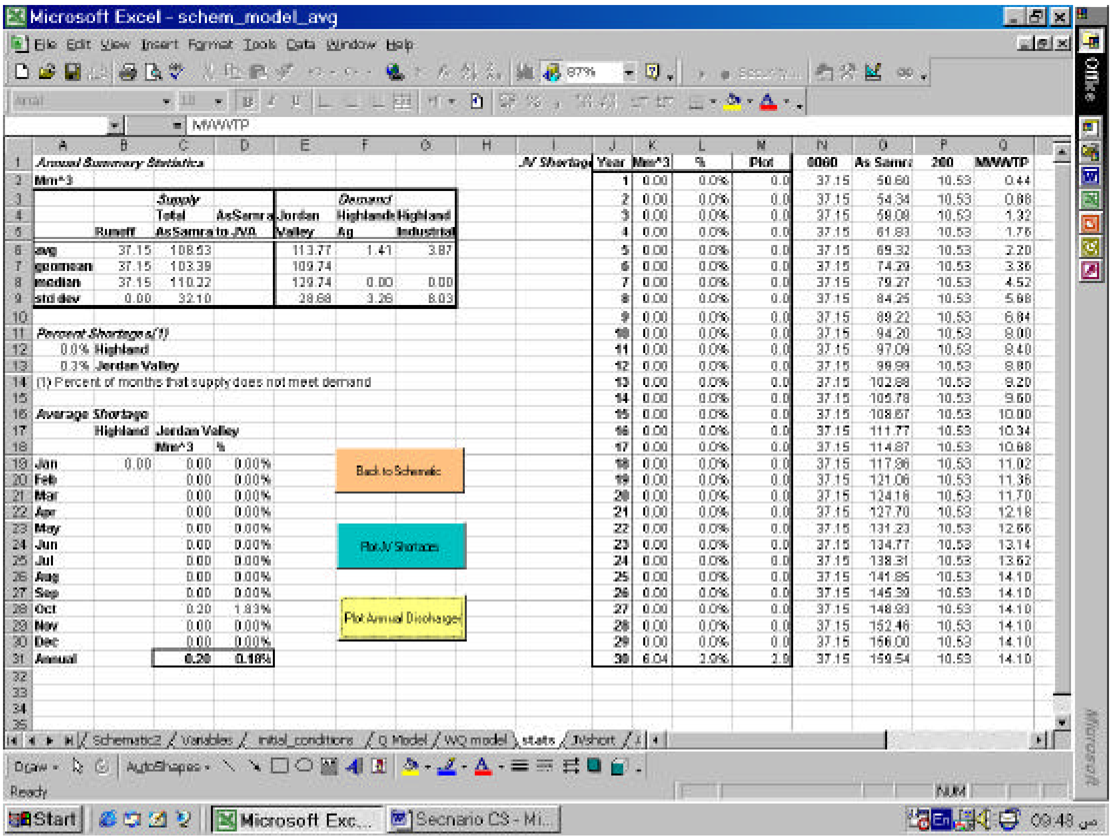


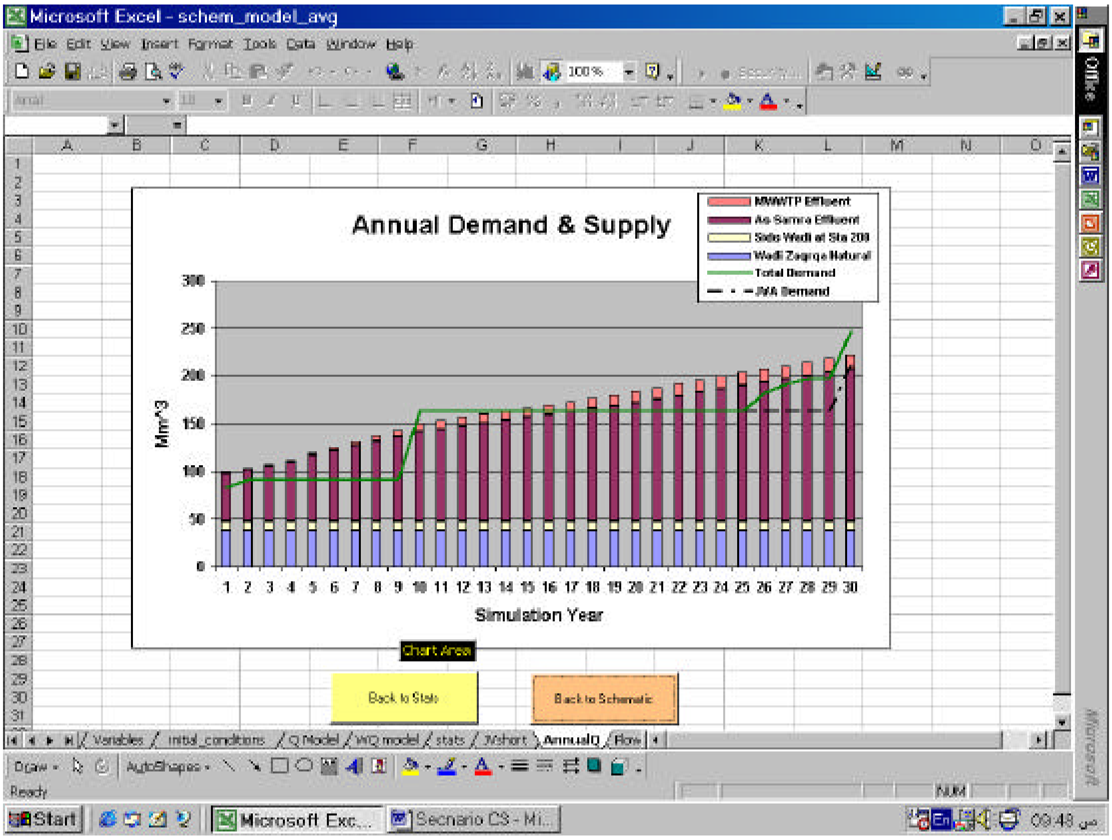



Microsoft Excel - schem_model_avg
Annual Demand & Supply
MWWTP Effluent
As Samra Effluent
Side Wadi at Sta 208
Wadi Zarqa Natural
Total Demand
JVA Demand
Mm^3
Simulation Year
Chart Area
Back to Stats
Back to Schematic

Output from Scenario C3






Annual Demand & Supply
MWWTP Effluent
As Samra Effluent
Side Wadi at Sta 208
Wadi Zarqa Natural
Total Demand
JVA Demand
Mm^3
Simulation Year
Back to Stats
Back to Schematic

APPENDIX F

TECHNICAL NOTE ON MICROBIOLOGICAL CONTAMINATION IN WADI ZARQA

INTERNAL TECHNICAL NOTE
WATER REUSE COMPONENT

December, 2000

The Water Resource Policy Support activity is supported by
The United States Agency for International Development (USAID) through a
Contract with Associates in Rural Development Inc.(ARD):
USAID/ARD Contract No. LAG-I-00-99-00018-00, Delivery Order No. 800

TABLE OF CONTENTS

F.1. INTRODUCTION

F.1.1. BACKGROUND

Fecal Coliform Concentrations (FCC) in the waters of Wadi Zarqa and the Jordan Valley are of considerable concern, especially as this water is used for irrigation, presenting potential health problems to the field workers and the members of the public who consume these irrigated crops.

The specific concerns that have been raised are:

- FCC levels in Wadi Dhuleil and upper Wadi Zarqa are higher than the effluent discharged from the wastewater treatment plant;
- Despite relatively low levels of FCC in the discharges from the King Talal Reservoir (KTR), the levels rise again before reaching the diversion point into the Jordan Valley; and
- Had the fencing of the King Abdullah Canal (KAC), completed in 1996, resulted in reduced FCC levels, thought to be caused by contamination from livestock and human encroachment on the canal.

F.1.2. OBJECTIVES

The objective of the analysis present here was to determine the recent historical characteristics of FCC levels in the Wadi Zarqa and King Abdulah Canal (KAC), specifically examining the temporal and spatial trends in:

- Wadi Duhleil and upper Wadi Zarqa (upstream of the King Talal Reservoir [KTR]);
- KTR and the lower Wadi Zarqa; and
- KAC upstream of the mixing point.

F.1.3. SCOPE & LIMITATIONS

This study was undertaken using existing data sets and information. The primary data sets were those obtained from the Royal Scientific Society (RSS), which were collected as party of their on-going contracts with the Water Authority of Jordan (WAJ) and the Jordan Valley Authority (JVA). The data sets obtained were those from 1994 through 1999, and comprised FCC samples for each month from a number of sampling points in the basin. The sampling points of interest are 3, 4, 5, 5.1, 6 and 7 in the upper basin; and 100, 300, 600, 650, 700, C1 and C2 in the lower basin, as shown in Figure F.1.

The data from each of these locations are relatively complete with the exception of stations 6 and 300. With the absence of comprehensive data from station 6, which represents the main stem of the Zarqa before its confluence with Wadi Dhuleil, it is not possible to be definitive about the relative contributions of the two wadis to downstream FCC levels. Also, the paucity of the data set from station 300 means that little can be said about the relative contribution of Jerash.

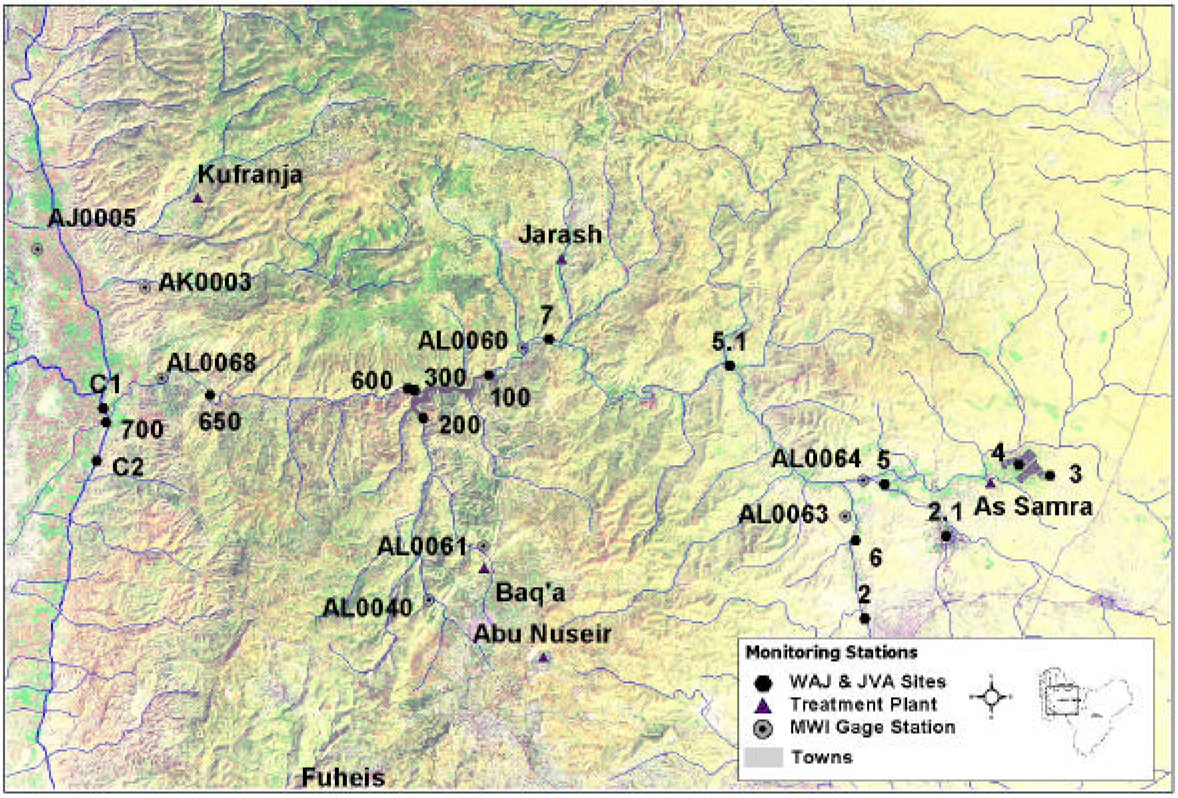


Figure F.1. Water Quality Sampling and Gaging Stations in Wadi Zarqa and the Jordan Valley

The Jordanian Standards for discharge to wadis, and for water reuse, drawing on recommendations from WHO guidelines, specify 1000-MPN as the upper limit for such practices. This is, to some extent, an arbitrary target that does not guarantee the safety of the water. However, given that this is the present target in Jordan, this is used in this study as an indicator of the relative risk with the water in Wadi Zarqa. Considering the end-use of the water in Wadi Zarqa, the two areas where FCC levels are of concern are the irrigated areas in the riparian lands along Wadi Dhuleil and Wadi Zarqa, and the middle and Karameh directorates of the Jordan Valley. The focus, therefore, is on possible high levels of FCC when water is supplied to these areas.

In analyzing FCC it is common practice to present the data as geometric mean rather than the arithmetic mean as one high measurement can distort the arithmetic mean. However, the use of the geometric mean can disguise the presence of a problem. In the analysis presented in the next section, the median is used to investigate the general trends, and the maximum and minimum values are used to depict the ranges. Finally, the analysis also considers the frequency of exceedance of the Jordanian Standard (1000 MPN), as discussed above.

F.2. REVIEW

Microorganisms exist everywhere in the environment. Few are a threat to human health. Many microorganisms are, in fact, beneficial, by enhancing soil fertility, degrading wastes, and removing pollutants. Some microorganisms live in or on the human body, often doing no harm and even being of some benefit. These microorganisms include the fecal indicator bacteria, which inhabit the gastrointestinal tract of humans and other warm-blooded animals. Generally, such microorganisms cause no harm. However, a few, called pathogens, can cause disease. They invade the body and, by either multiplying or producing toxins, interfere with the body's processes. The presence of fecal coliform, which occur in the feces of warm-blooded animals in higher concentrations than pathogens, indicates that disease causing pathogenic organisms could be present.

Fecal indicator bacteria, depending on the environment, can survive from a few hours up to several days in water, but may survive for days or months in sediments, where they may be protected from sunlight and predators. It is generally assumed that pathogens die at the same rate as fecal indicator bacteria.

F.3. ANALYSIS

This chapter presents the analysis and results from the examination of the Upper Wadi Zarqa, including Wadi Dhuleil; the Lower Wadi Zarqa, including KTR; and KAC.

F.3.1. UPPER WADI ZARQA, INCLUDING WADI DHULEIL

<u>Overview</u>

Even when the FCC levels in the effluent from As Samra, because of final disinfection, the levels in the upper Wadi Zarqa, including Wadi Dhuleil, were higher. These high levels of FCC in the receiving body were used as part of the justification for ceasing the final disinfection from the As Samra facility (as of 1996). The risk of generating chlorine based toxins from adding chlorine to an effluent with high biological contamination (BOD > 170-mg/l) was also, apparently, a consideration, although it is unlikely that these waters will contaminate drinking water supplies

<u>Available Data</u>

The RSS/WAJ water quality monitoring stations of interest, are 4, 5, 5.1, 6 and 7, although, as mentioned above, the data set from station 6, which is that on the main branch of the Wadi Zarqa upstream of the confluence with Wadi Dhuleil, is limited.

<u>Analysis</u>

Figure F.2 depicts median monthly FCC levels from As Samra until the Zarqa river discharges into KTR for 1994 through 1999. Final chlorination of the effluent was stopped in 1995, which, as can be seen, resulted in the FCC levels in the final effluent rising by over two orders of magnitude.

One of the reported reasons for ceasing the final disinfection of the effluent was that the FCC levels in wadi Dhuleil downstream of the discharge point were already as high as the undisinfected effluent. This phenomenon is confirmed by the data for 1994. Although a targeted study will be required to confirm the sources of this contamination, there are a number of chicken and dairy farms between the two sampling points and, most likely, there is potential for leakage from sewers and septic tanks in the upper basin.

The differences in values between sampling stations 4 and 5, and 100 confirm that the wadi itself does reduce the FCC levels. However, the FCC levels reaching KTR are still an order of magnitude greater than Jordanian Standards for irrigation with effluent (1000 MPN). According to the standards, the water from the upper wadi Zarqa should not be used for any irrigation at all.

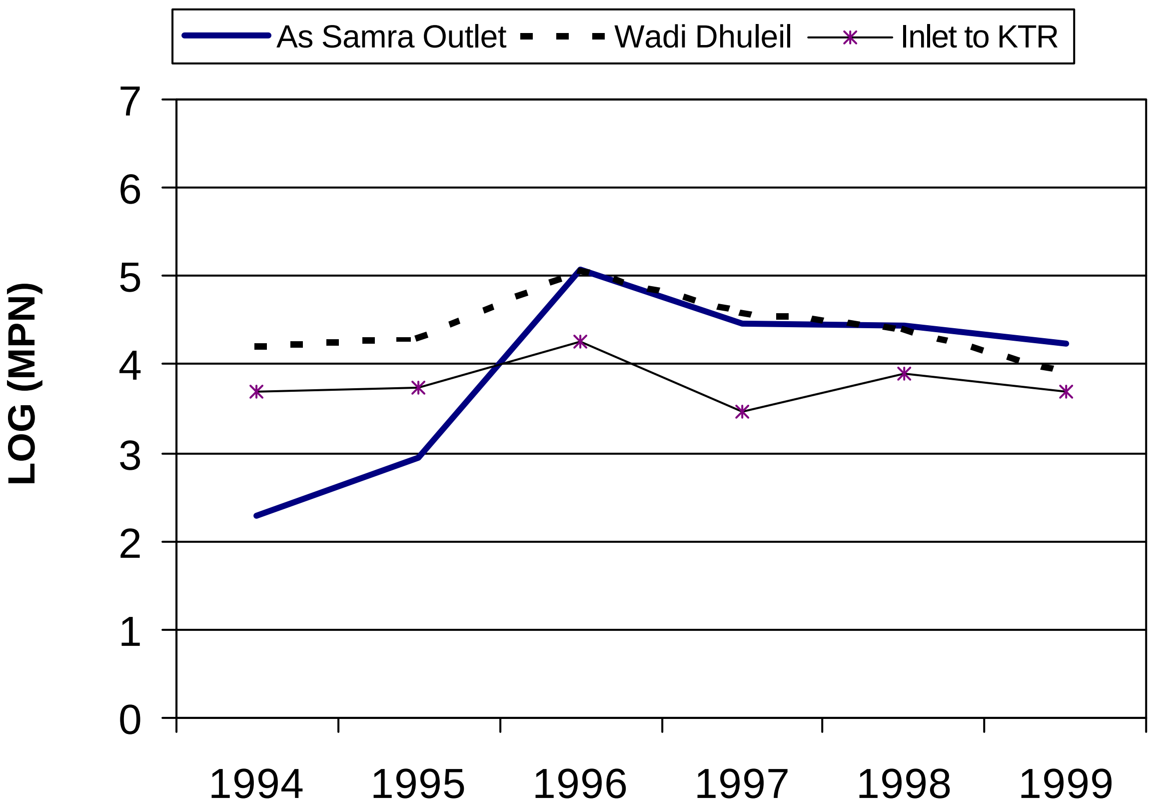


Figure F.2. Median monthly FCC levels at the As Samra wastewater treatment facility [Sampling point 4], Wadi Dhuleil downstream of As Samra [Sampling point 5], and immediately upstream of King Talal Reservoir [Sampling point 100].

F.3.2. LOWER WADI ZARQA

Figure F.3 shows the median monthly FCC values for water discharged from KTR (sampling point 600), sampling point 650, which is 10-km downstream of the reservoir, and sampling point 100, immediately upstream of the reservoir.

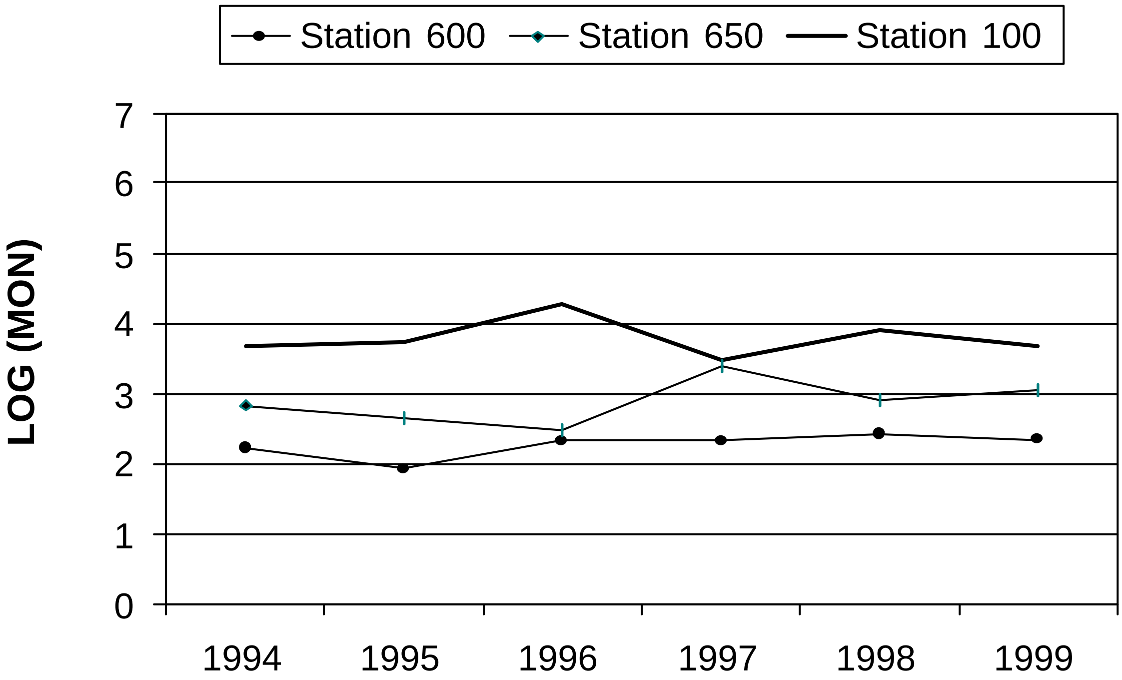


Figure F.3. Median monthly FCC levels immediately upstream of King Talal Reservoir [Sampling point 100], at the KTR outlet (Sampling point 600), and 10-km downstream of KTR [sampling point 650].

The difference between the values for station 600 and 100 demonstrates the effect of the reservoir on reducing the FCC levels below the Jordanian Standard for irrigation with recycled water (1000 MPN). However, as reported, the increase from station 600 and 650 shows that the water in wadi Zarqa downstream of KTR is, generally, just in compliance. This recontamination appears to be due to either human or animal waste from the side wadis.

The implication of results from sampling point 650 is that the FCC levels in the KTR water reaching the Jordan Valley are, generally, just in compliance with the Jordanian Standards for irrigation with recycled water. However, considering the range of FCC values in any given year, as summarized in Figures F.4 and F.5. the KTR water reaching the Jordan Valley is not in compliance over thirty percent of the time.

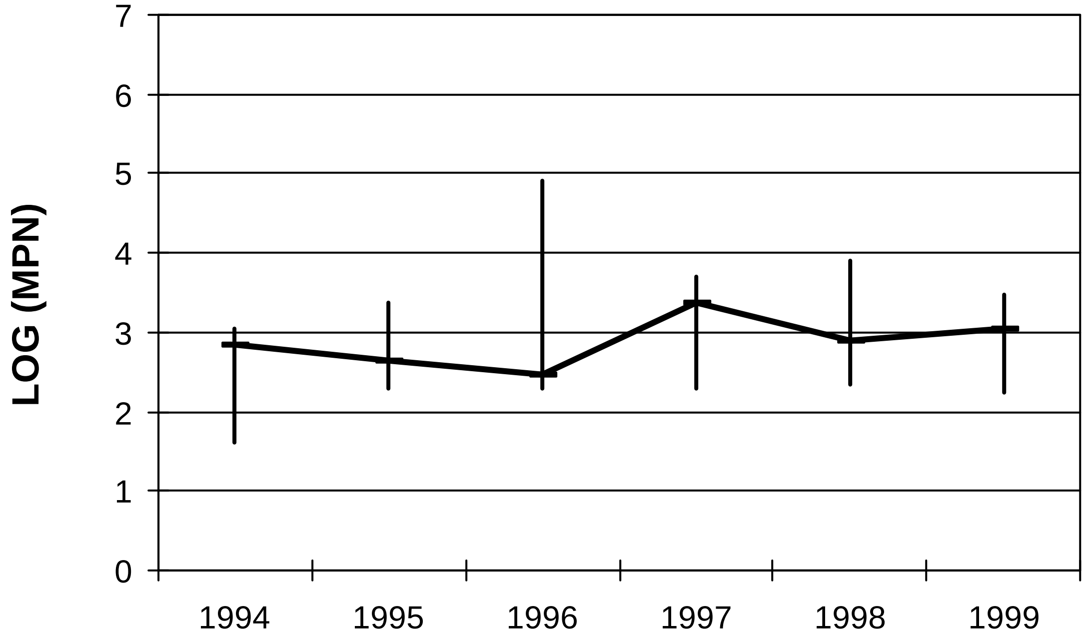


Figure F.4. Ranges (maximum, median & minimum) of monthly FCC levels 10-km downstream of KTR [sampling point 650].

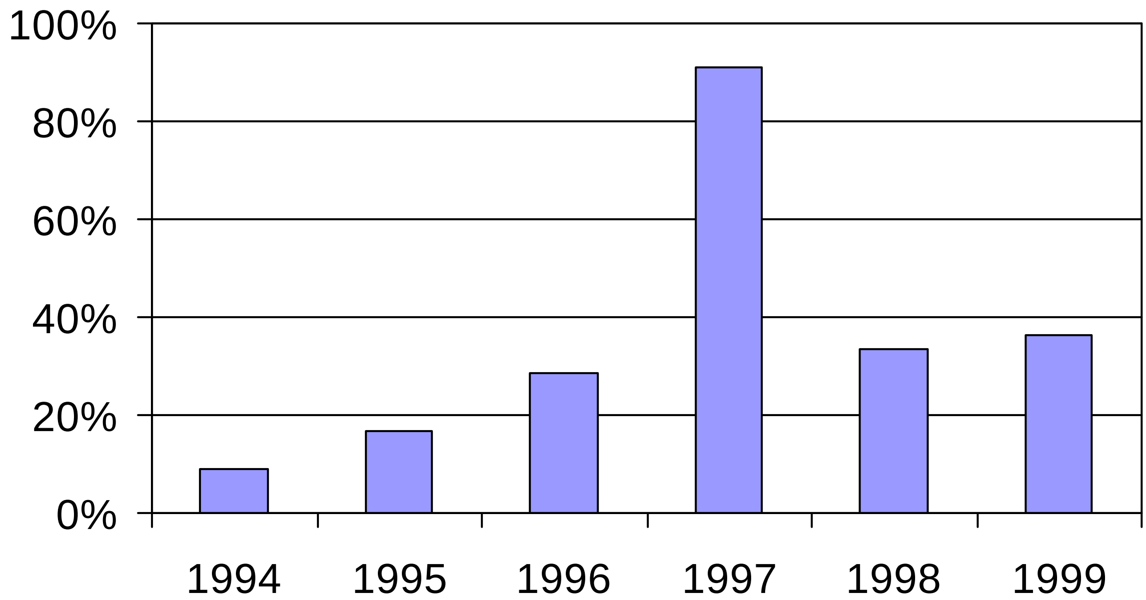


Figure F.5. Frequency that FCC levels at sampling point 650 (10-km downstream of KTR) failed to comply with the Jordanian Standard for irrigation with recycled water.

The reservoir does reduce the FCC levels in the water impounded, but the effectiveness of this process does depend on the time of year. Figure F.6 compares the monthly FCC values for immediately upstream of the reservoir with those at the outlet. Notice, that, in general, the FCC levels at the outlet rise from very low levels in October, to levels that can exceed the Jordanian Standards in December/ January. The elevated levels coincide with the on set of the wet season when large volumes of runoff water are entering the reservoir and retention times are low.

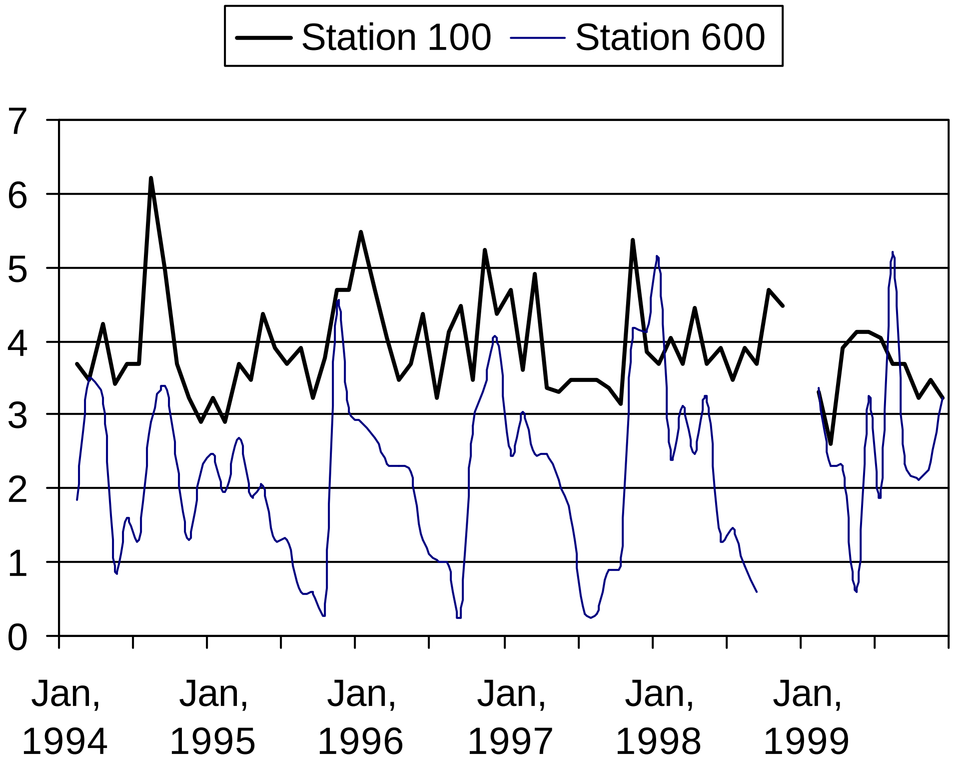


Figure F.6. Comparison of monthly FCC levels immediately upstream and downstream of the King Talal Reservoir.

F.3.3. KING ABDULLAH CANAL

Figure F.7 shows that the median FCC level in the King Abdullah Canal has been trending downwards. Lower levels would suggest the fencing has worked, but a gradual downward trend indicates that other factors may be involved. Despite this downward trend, there are months where the FCC levels are greater than 1000 MPN, indicated by the maximum of the ranges.

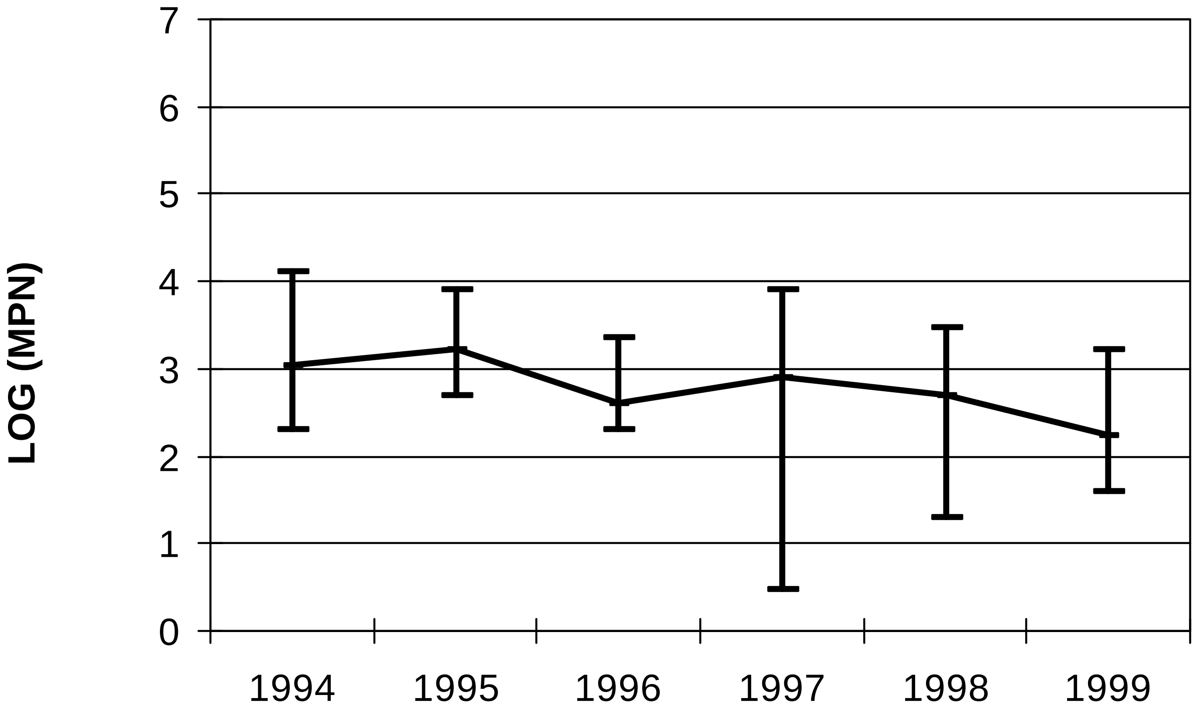


Figure F.7. King Abdullah Canal FCC levels (monthly maximum, median and minimum) upstream of the mixing point (C1).

F.4. CONCLUSIONS

Microbiological contamination from sources other than the As Samra wastewater treatment plant meant that, even when the effluent from As Samra received final disinfection (before 1996), the fecal coliform levels in the wadi water were high.

Fecal coliform levels in water discharged from King Talal Reservoir are, generally, low. However, by the time this water reaches the Jordan Valley it has been recontaminated. It is most likely that this recontamination comes from secondary sources discharging into the tributaries of the wadi.

In addition, if the reservoir is low during the wetter months of December, January and February, microbiologically contaminated runoff from the upper basin is not retained for a sufficient period in the reservoir to allow for die off of the fecal coliform. This results in releases to the Jordan Valley that can be above the Jordanians Standards for reuse.

Accounting for both the above phenomena, the fecal coliform levels in the water reaching the Jordan Valley from Wadi Zarqa exceeds the Jordanian Standards for reuse about 30 percent of the. It is interesting to note that neither of these phenomena is directly related to effluent being released from wastewater treatment plants. In both cases, the contamination is coming from secondary sources. On the other hand, in Wadi Zarqa upstream of the reservoir, the water is contaminated with less than adequately treated wastewater from As Samra. When As Samra is upgraded, the fecal coliform levels in wadi Zarqa are not expected to improve.

Although fencing of King Abdullah canal would appear to have produced a reduction in FCC over time, the overall FCC remains above the 1000 MPN. Also, it is interesting to note that the FCC levels have declined over a number of years rather than a noticeable step reduction in fecal coliform levels, which would be more consistent with the completion of a fence.

APPENDIX G

RWAM-AZB WATER QUALITY RESULTS FOR SCENARIO C1-C3

Water Quality (General)

Water quality is expected to be impacted primarily by two considerations; one is improved quality of As Samra effluent compared to current quality; the second is the relative increase of As Samra flows to natural flow proportions. For model simulation runs initial concentrations of water quality variables at As Samra were set to the either the Jordanian standard, when current levels exceeded the standard, or at current average levels for those variable not currently exceeding the standards.

As the ratio of As Samra flows to natural flow increases, water quality will become more consistent as recycled water will become more consistent in quality after As Samra is rehabilitated and expanded.

Those scenarios that maintain a consistently higher level of water in KTR or additional storage are expected to have better water quality than those scenarios that drawdown KTR and/or any proposed storages severely and repeatedly.

TDS and Chloride

TDS and Chloride is expected to increase slightly over time as As Samra flows become more dominant. As salt and chloride levels from As Samra are expected to be only slightly higher than those in natural flow, this increase is expected to be small. Seasonal variability is expected as concentration of salts and chlorides vary with Wadi Zarqa discharge. High flows during the runoff season from November through March have lower concentrations of salts than do the summer months. Seasonal variability of salt and chloride is expected to decrease over time due to increased As Samra flows which are expected to be consistent in quality.

Ammonium and Nitrate

Ammonium is expected to decrease in a downstream fashion as it has historically due to oxidation to nitrite and nitrate. By the same reasoning, nitrate is expected to increase in a downstream manner. Travel time from As Samra to KTR is normally about 18 hours (Harza, 1996). During this relatively short period, very little organic nitrogen is expected to be converted to an inorganic form (Ammonium). As such, the sum of Ammonia-N and Nitrate-N is expected to remain relatively constant moving downstream. Inputs of nitrogen from side wadis would change the mass balance. Little denitrification is expected to occur in Wadi Zarqa as it is fairly well aerated for most of its course (Harza, 1996).

Within KTR, consumption of ammonia and nitrate by algae and aquatic vegetation is expected to reduce total nitrogen. In addition, some denitrification will contribute to the loss of nitrate. Nitrate is expected to dramatically decrease between inflow and outflow from KTR or any proposed reservoir as it has historically through KTR.

Reservoir level has an impact on Total nitrogen and nitrogen form. As reservoir levels decrease, nitrate reduction within the reservoir lessens due to lower detention time and therefore nitrate levels are closer to inflow levels.

Total phosphorus

Total Phosphorus concentration in the outflow from KTR and from any proposed reservoir is expected to decrease from inflow concentrations. This is primarily due to soil adsorbed phosphorus and sedimentation within the reservoir. Additionally, some uptake of dissolved phosphorus is expected from algae or aquatic vegetation. Total phosphorus reduction is decreased by lower reservoir levels and, thus, shorter detention times.

Specific Scenarios

Results from the water quality model portion of RWAM-AZB are meant to show trends and relative changes as various scenarios are implemented. Natural variability in the physical system, as well as model uncertainty, mean that values generated by the model should be treated as a "best estimates" and not considered as "100% accurate".

Inflow concentrations that are constant are reflective of the constant As Samra water quality assumed in this analysis, and rate constants that do not vary by season. Reservoir beginning of month storage is shown with the water quality graphs since storage levels impact water quality change between inflow and outflow, and insight can be gained by looking at reservoir levels over the course of the simulation.

Scenario C1

Figure G-1 shows expected KTR levels over the simulation period. Figures G-2 to G-7 give an indication of expected water quality entering and exiting KTR for this scenario while Figures G-8 to G-10 do likewise for Station 650. Note that total Phosphorus does not decrease as much through the reservoir as KTR levels drop. NH4-N and NO3-N follow the same pattern. Average TDS and Chloride levels trend very slightly upward over the course of the simulation due to increased As Samra flows. Seasonal fluctuation of water quality variables is expected.

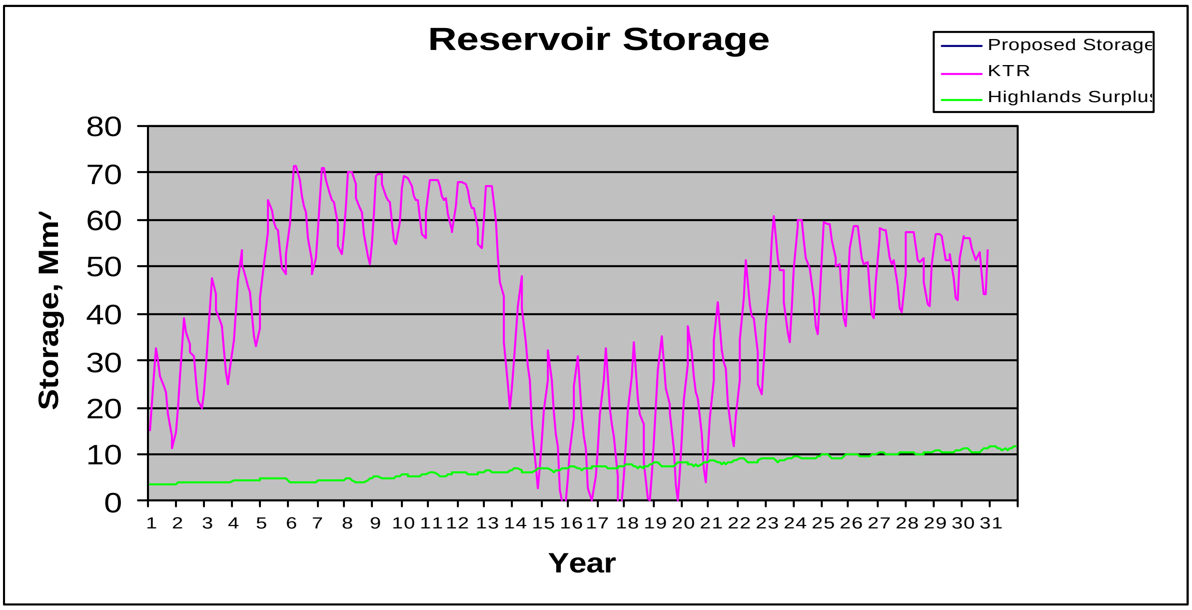


Figure G-1. Projected KTR Storage, Scenario C(1)

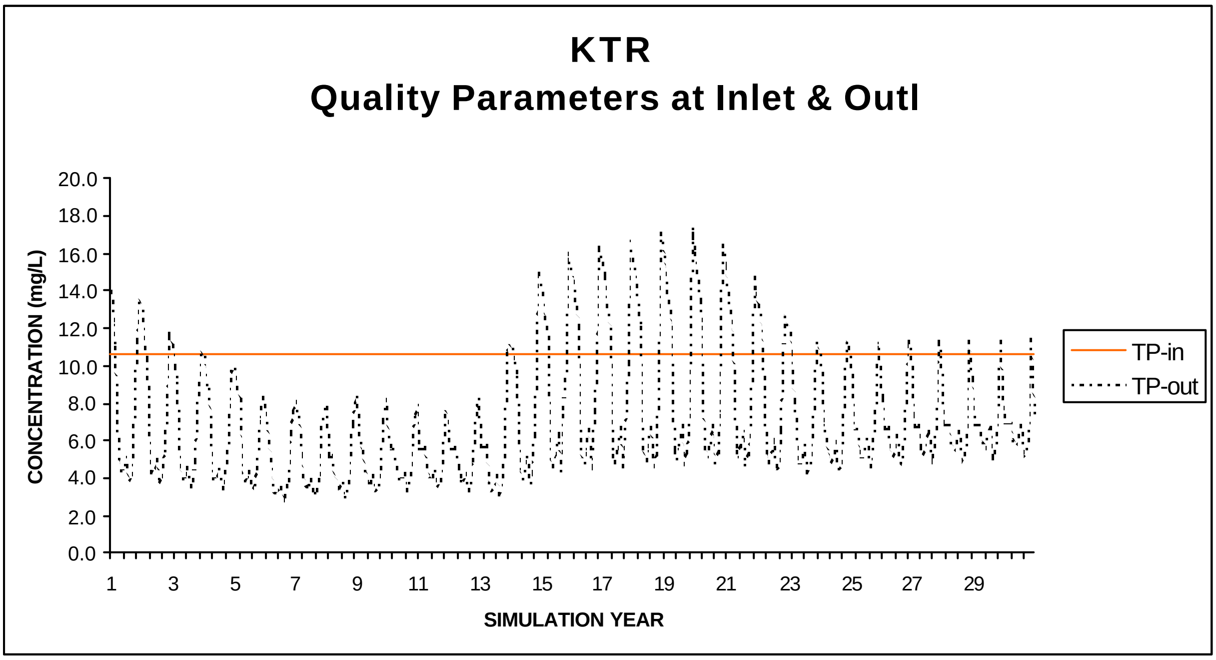


Figure G-2. Projected Total Phosphorus Concentration, in KTR Inflow and Outflow, Scenario C(1)

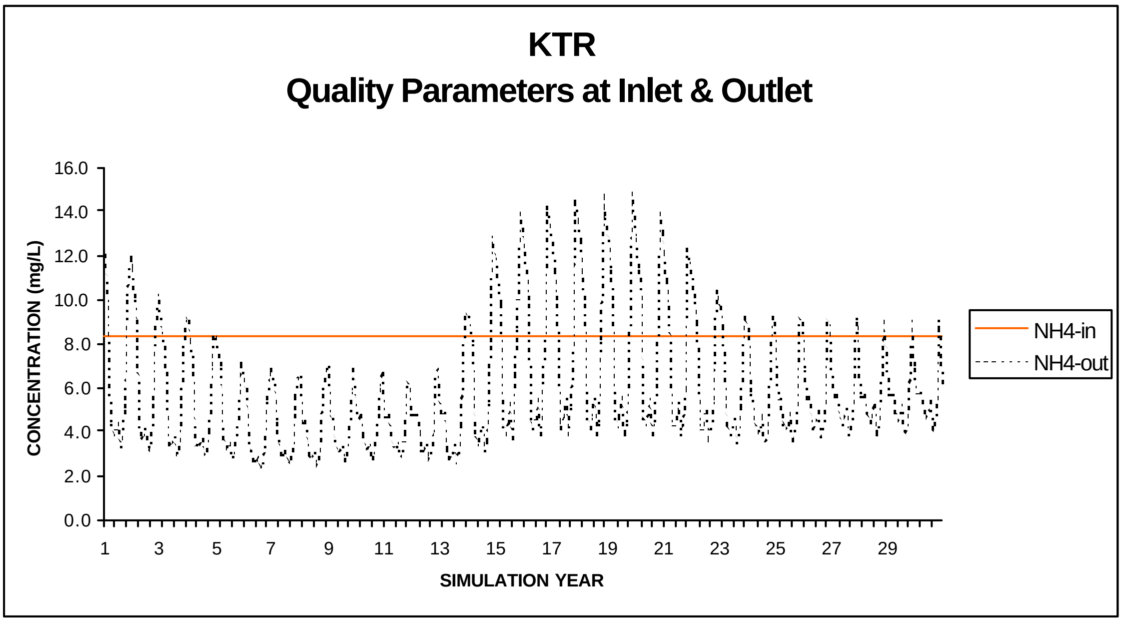


Figure G-3 Projected Ammonium Concentration, in KTR Inflow and Outflow, Scenario C(1)

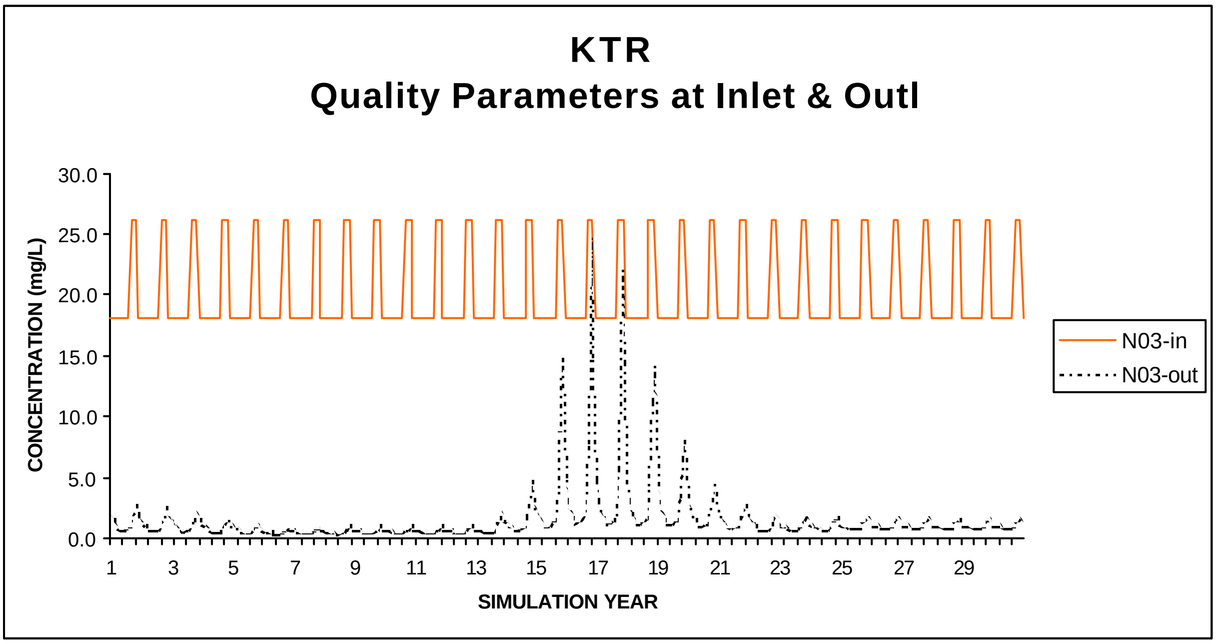


Figure G-4 Projected Nitrate Concentration, in KTR Inflow and Outflow, Scenario C(1)

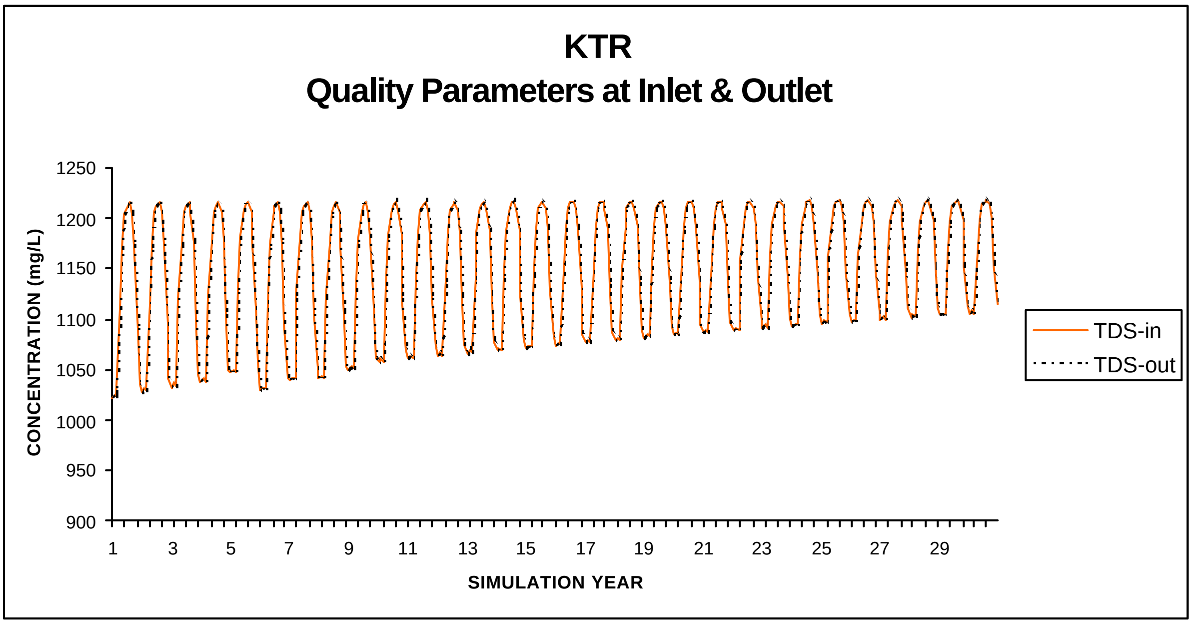


Figure G-5 Projected TDS Concentration, in KTR Inflow and Outflow, Scenario C(1)

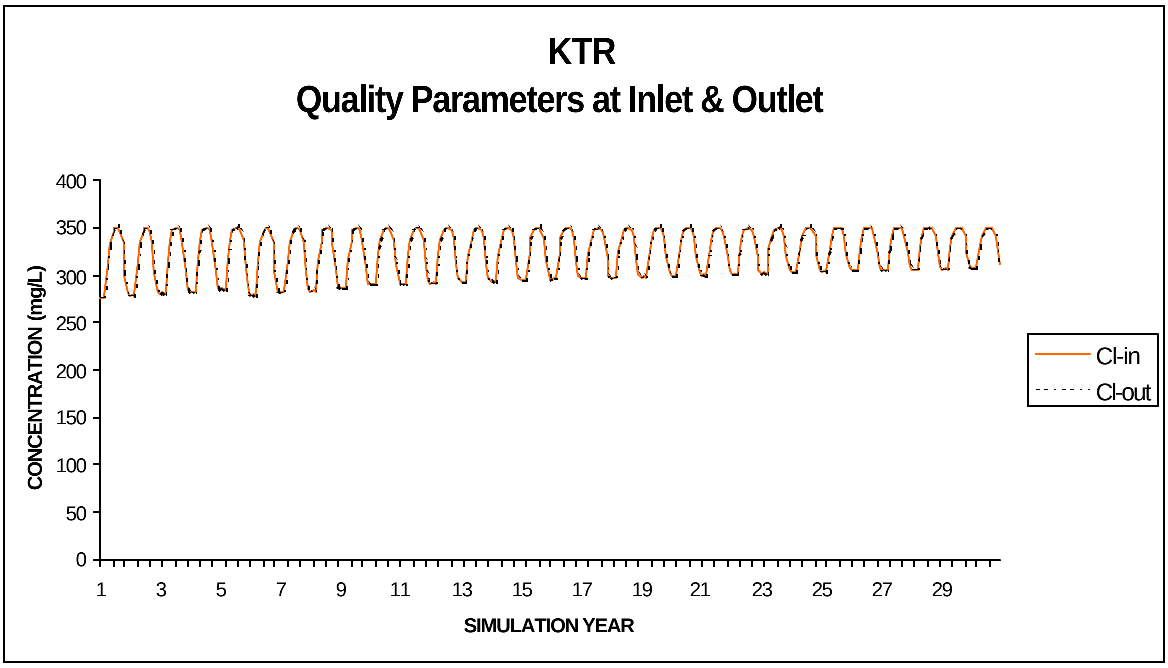


Figure G-6 Projected Chloride Concentration, in KTR Inflow and Outflow, Scenario C(1)

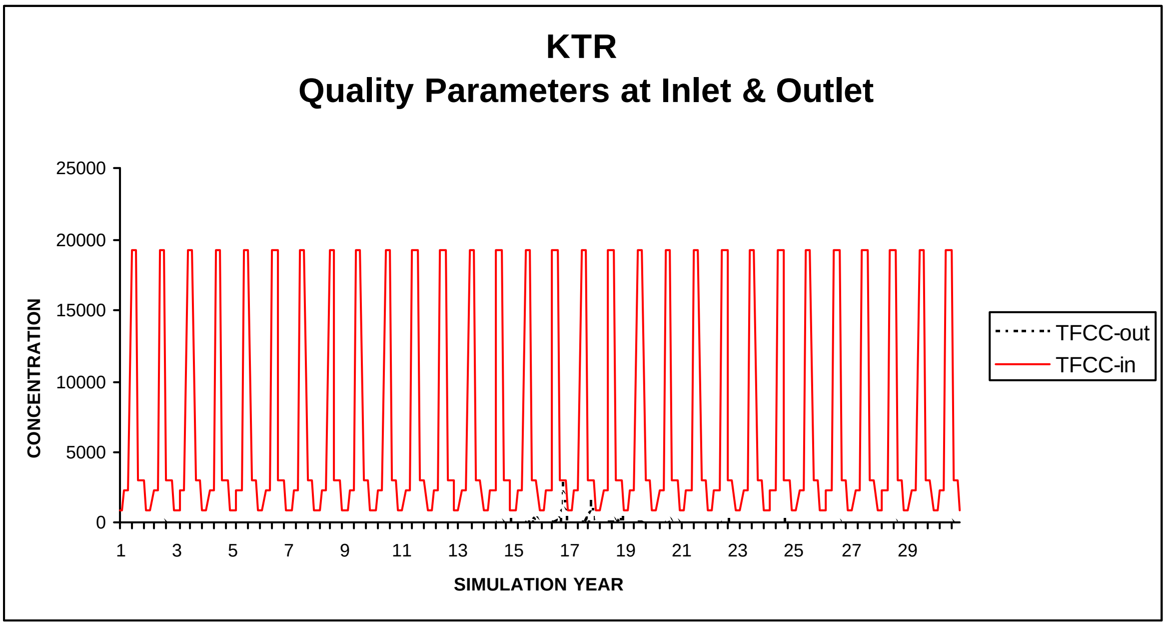


Figure G-7 Projected Total Fecal Coliform Concentration, in KTR Inflow and Outflow, Scenario C(1)

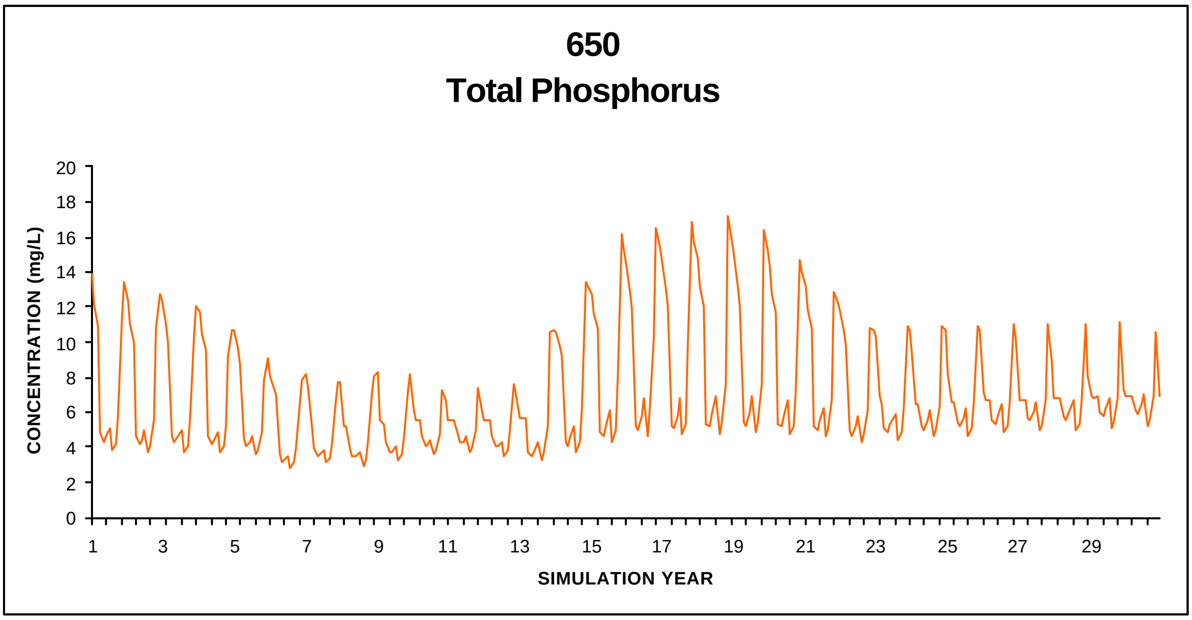


Figure G-8. Projected Total Phosphorus Concentration at Station 650, Scenario C(1)

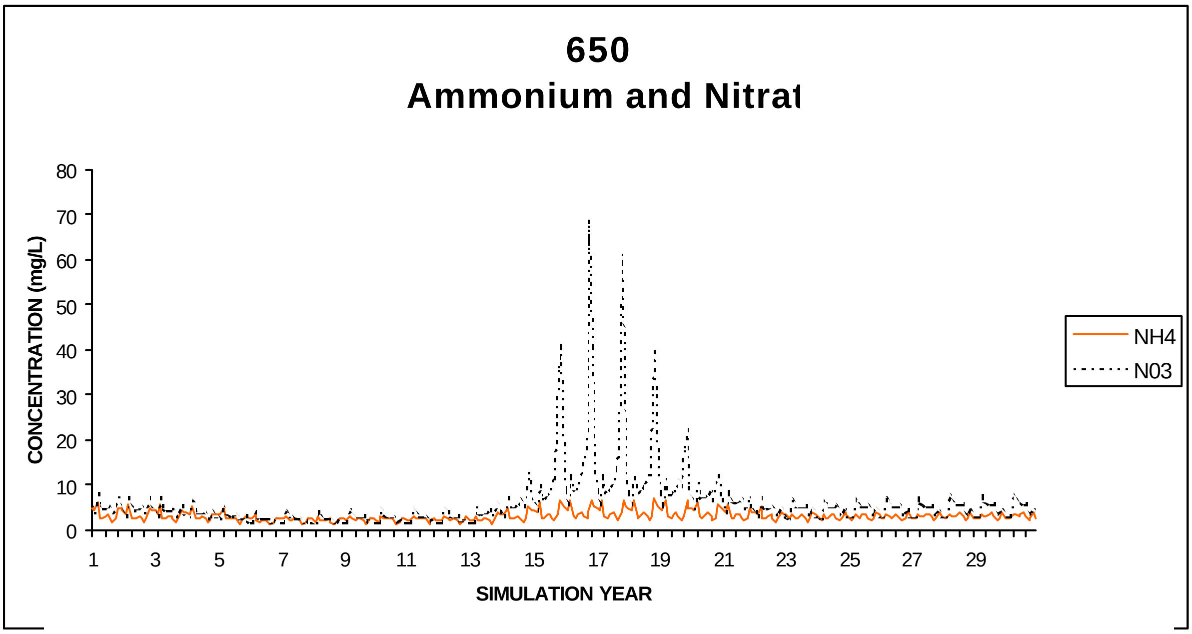


Figure G-9 Projected Ammonium-N and Nitrate-N Concentration at Station 650, Scenario C(1)

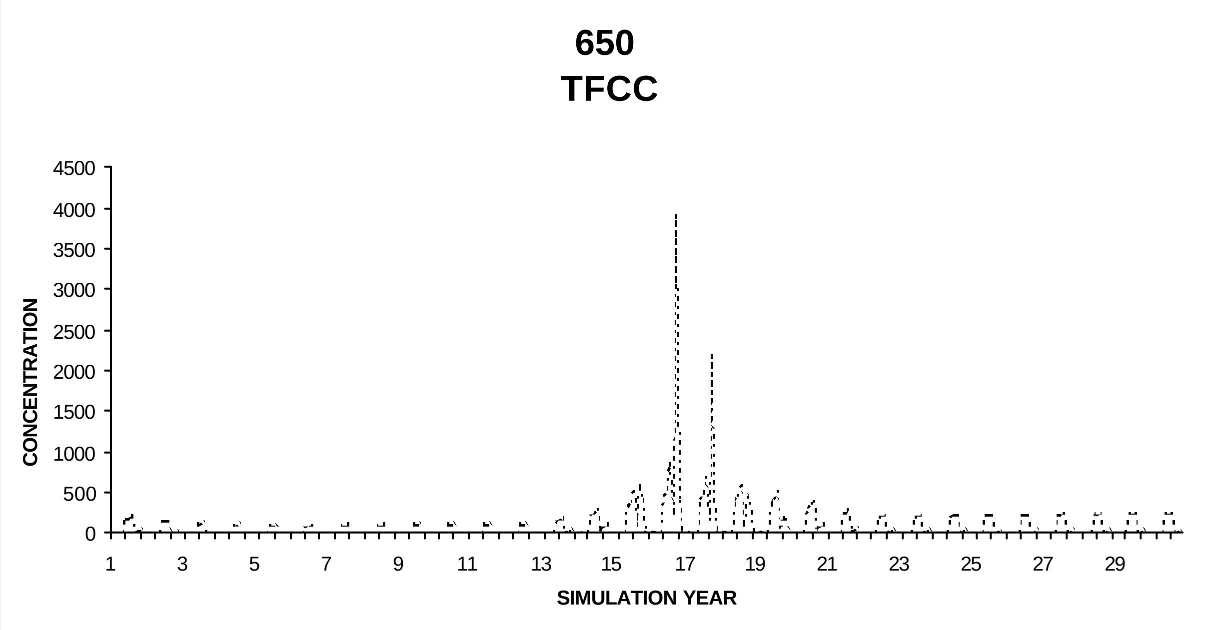


Figure G.10. Projected Fecal Coliform Count Concentration at Station 650, Scenario C(1)

Scenario C(2)

Scenario C(2) maintains higher water quality than Scenario C(1) since KTR is maintained at a higher level in Scenario C(2) than in Scenario C(1). Seasonal fluctuations in water quality are expected as in Scenario C(1). Figure G-11 shows KTR levels over the simulation period, while Figures G-12 through G-16 show expected water quality in KTR inflow and outflow. Figures G-17 to G-20 show expected water quality at Station 650 for this scenario.

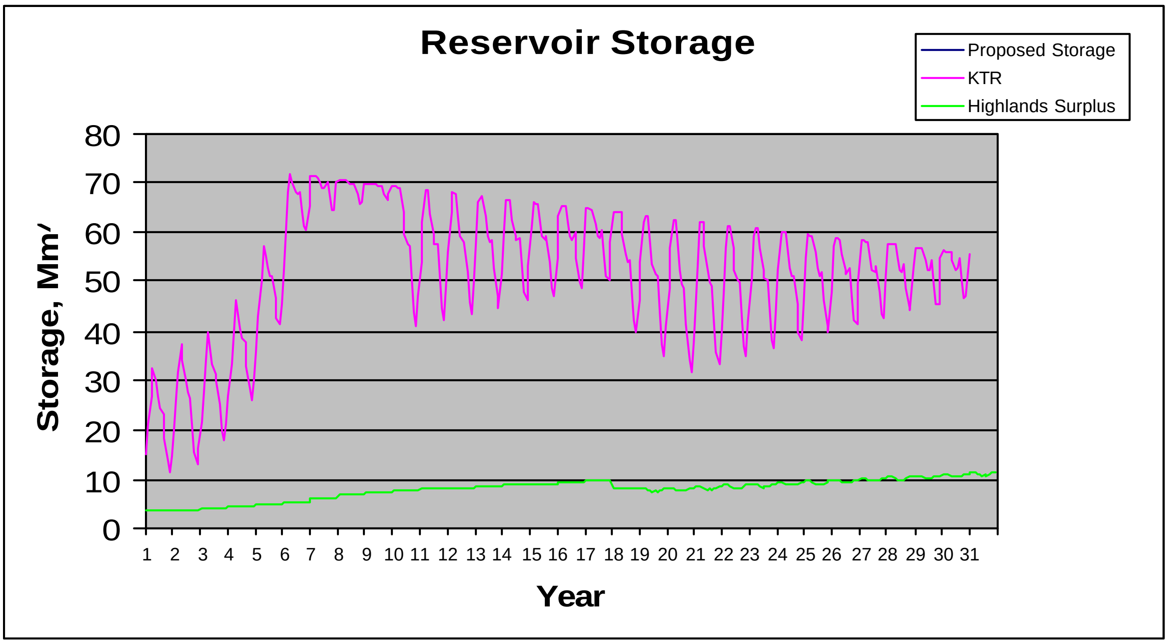


Figure G-11 Projected KTR Storage, Scenario C(2)

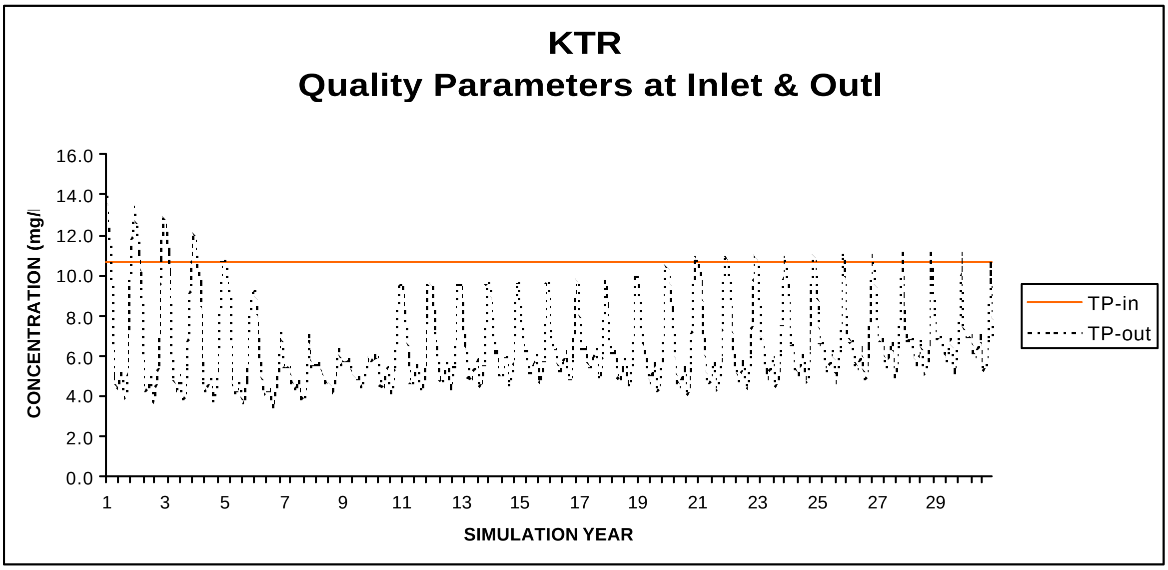


Figure G.12. Projected Total Phosphorus Concentration in KTR inflow and Outflow, Scenario C(2)

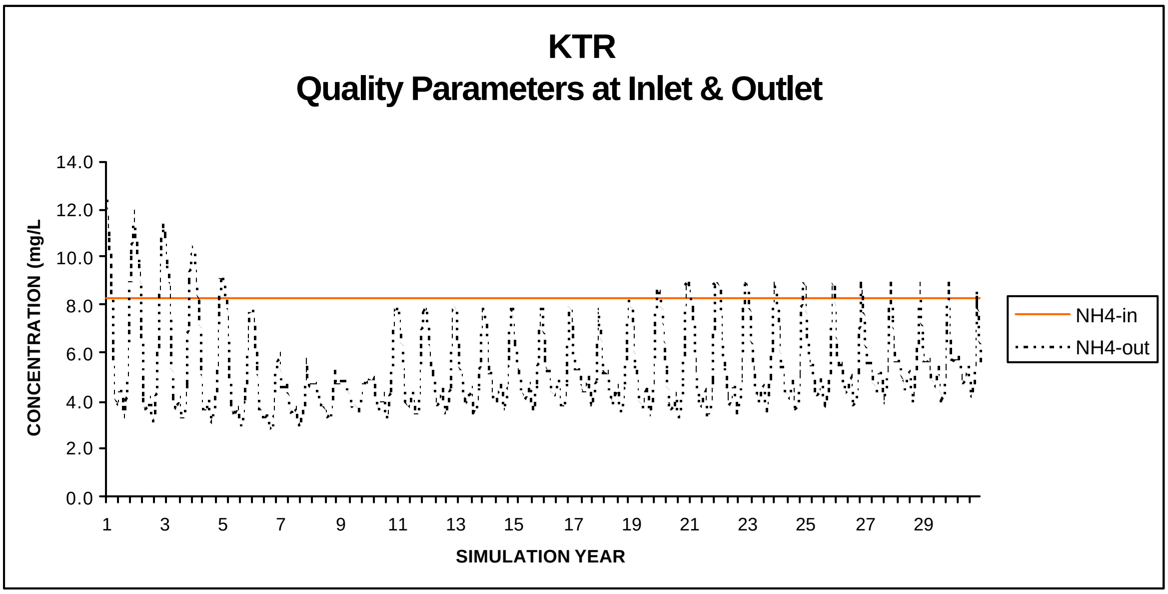


Figure G.13. Projected Ammonium-N Concentration, in KTR Inflow and Outflow, Scenario C(2)

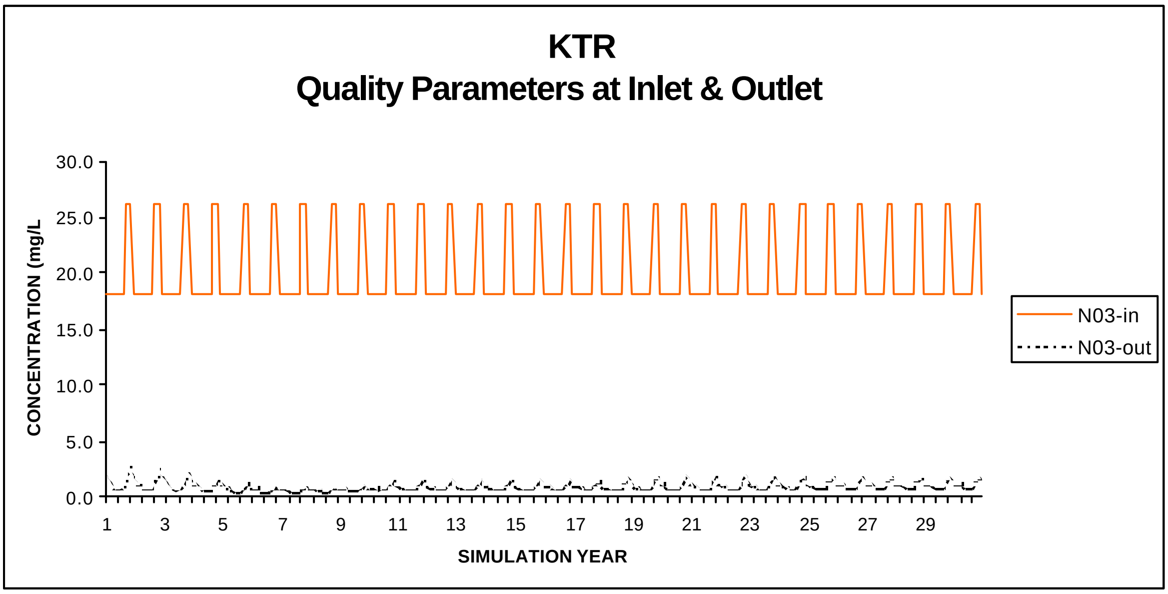


Figure G.14. Projected Nitrate Concentration, in KTR Inflow and Outflow, Scenario C(2)

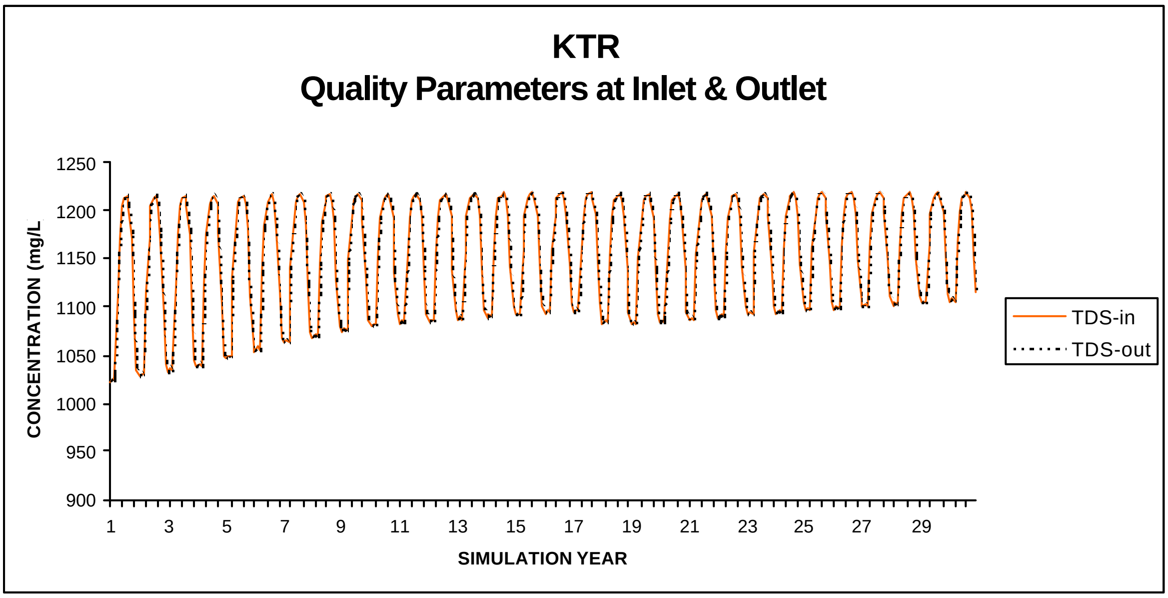


Figure G.15. Projected TDS Concentration, in KTR Inflow and Outflow, Scenario C(2)

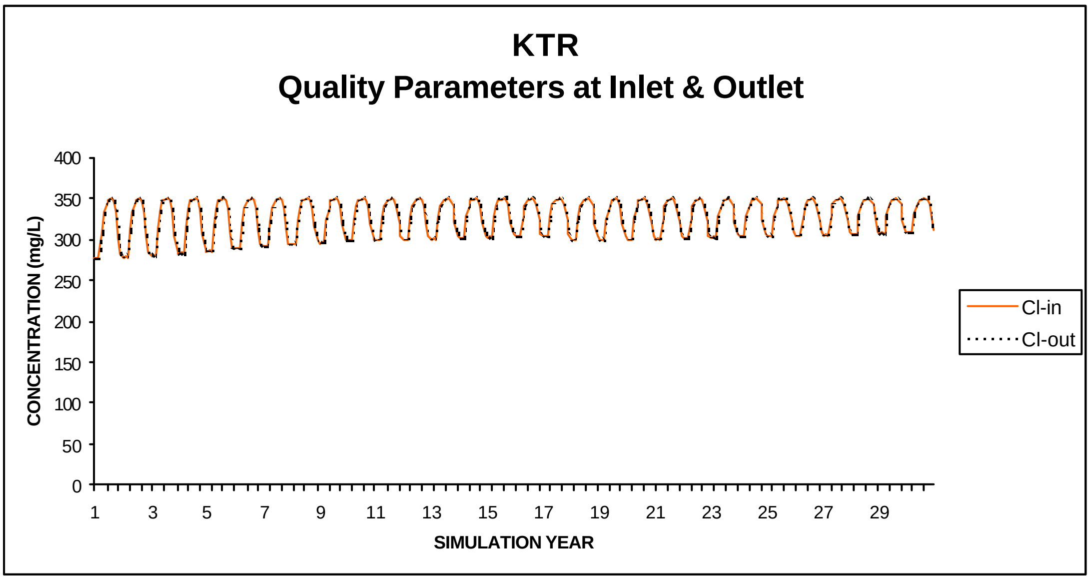


Figure G.16. Projected Chloride Concentration, in KTR Inflow and Outflow, Scenario C(2)

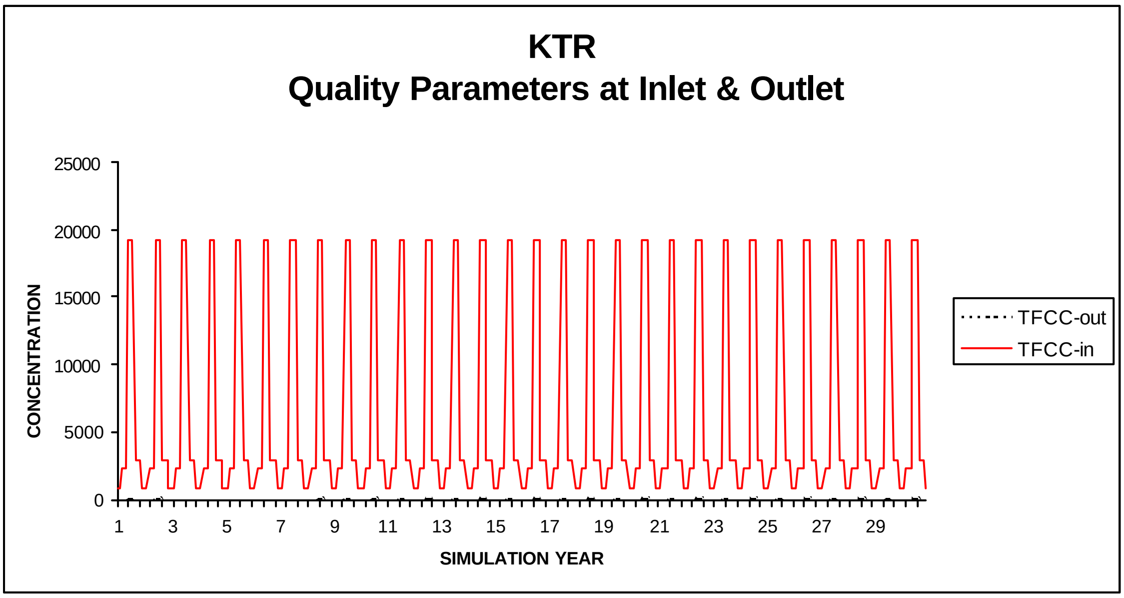


Figure G.17. Projected Fecal Coliform Count Concentration in Inflow & Outflow of KTR, Scenario C(2)

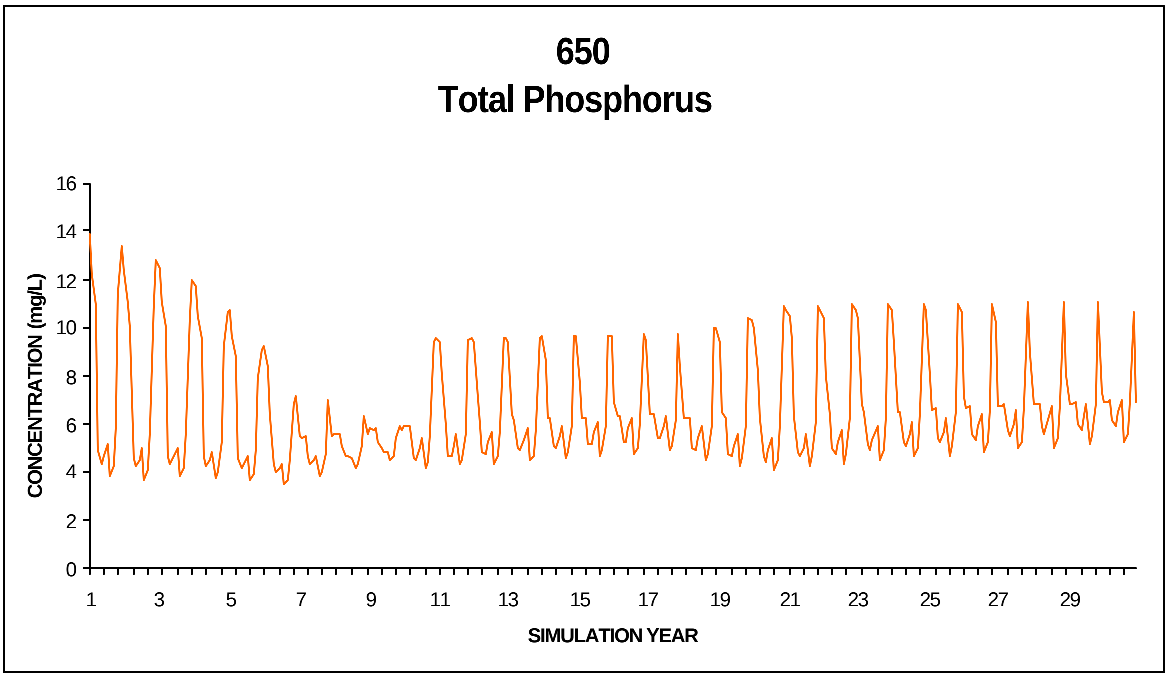


Figure G.18. Projected Total Phosphorus Concentration at Station 650, Scenario C(2)

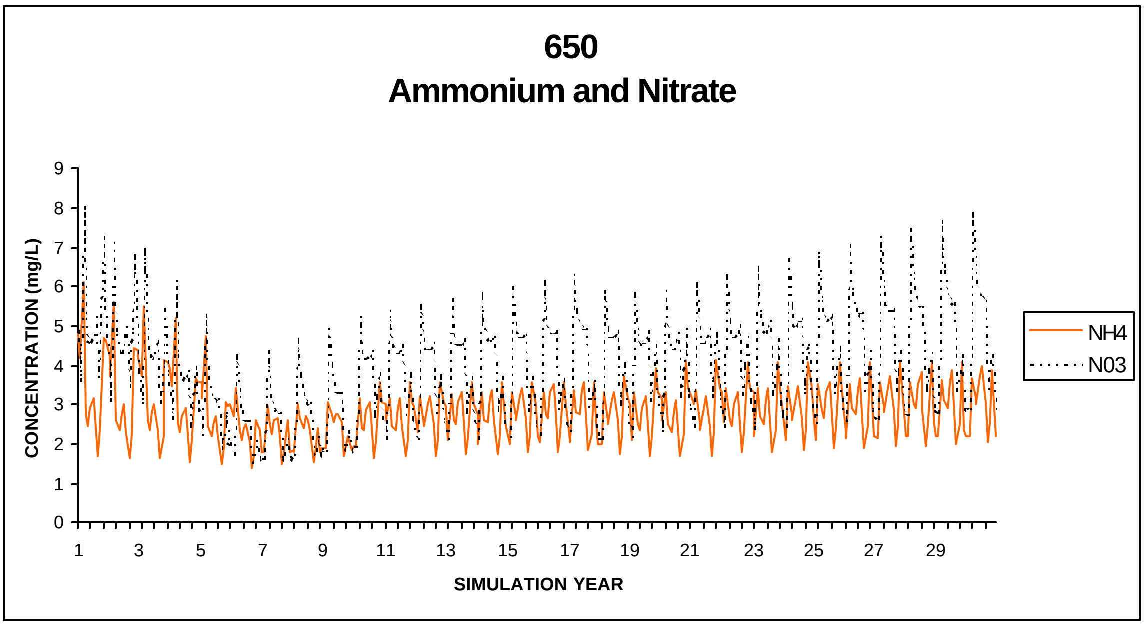


Figure G.19. Projected Ammonium-N and Nitrate-N at Station 650, Scenario C(2)

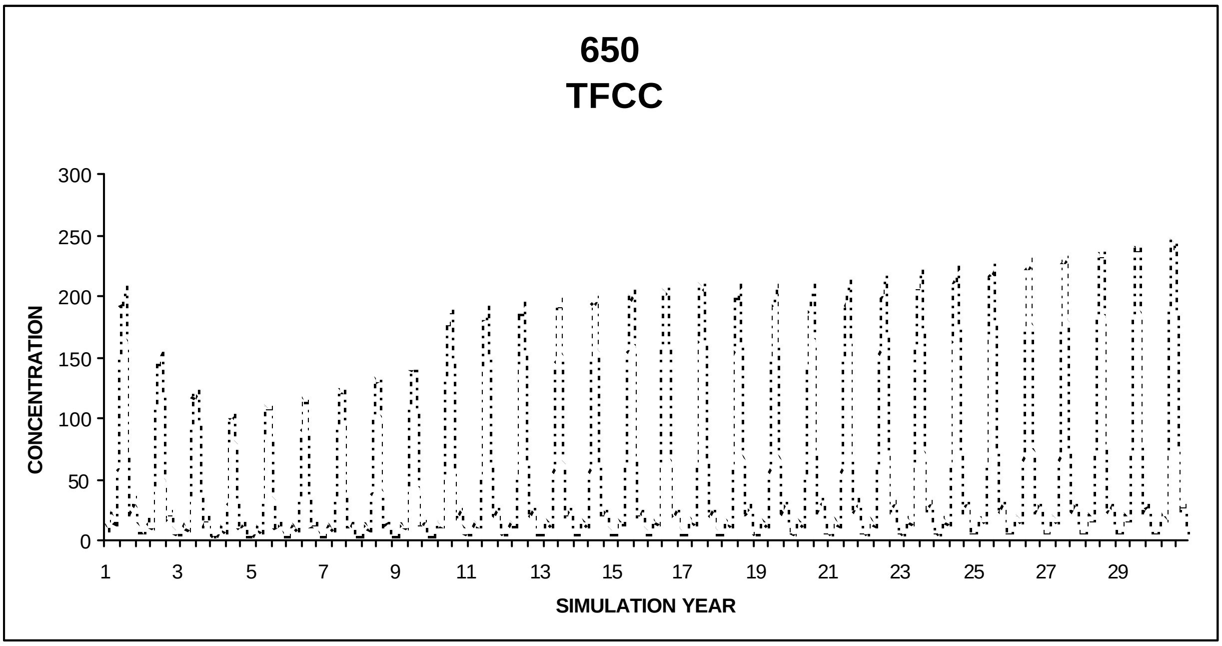


Figure G.20. Projected Fecal Coliform Count at Station 650, Scenario C(2)

Scenario C3

Water Quality worsens during the middle and at the very end of Scenario C(3) as KTR storage drops. General seasonal trends and responses to KTR levels are similar to scenarios C(1) and C(2). Figure G-21 shows KTR levels for the simulation period, and Figures G-22 through G-25 show expected water quality for this scenario. Figures G-26 to G-28 show expected water quality at Station 650 under this scenario.

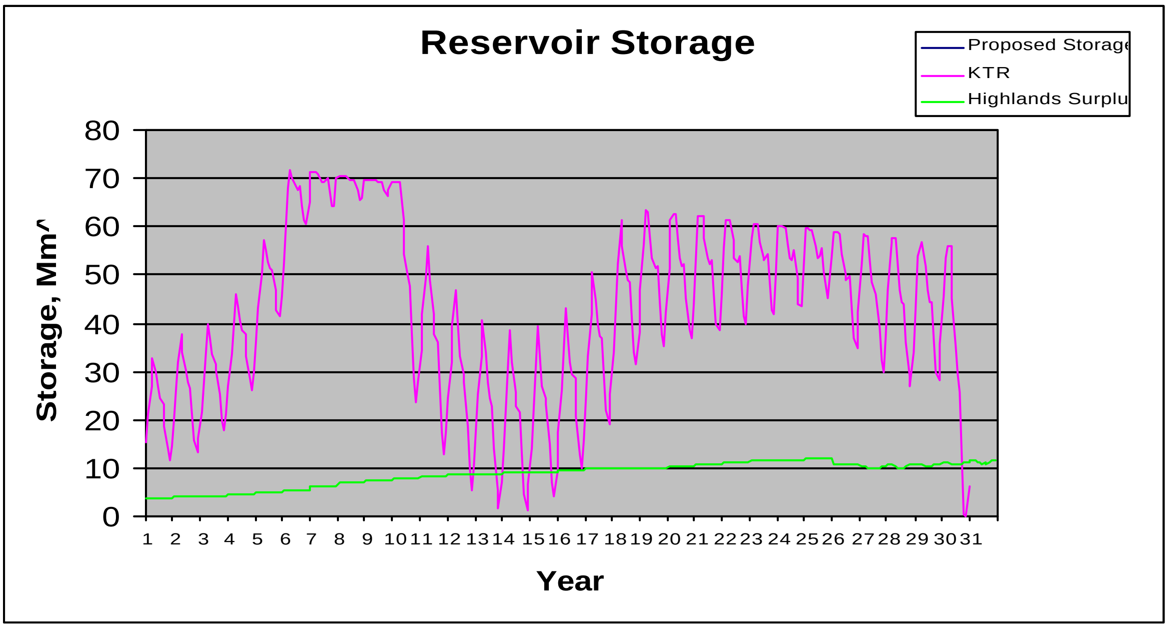


Figure G-21 Projected KTR Storage, Scenario C(3)

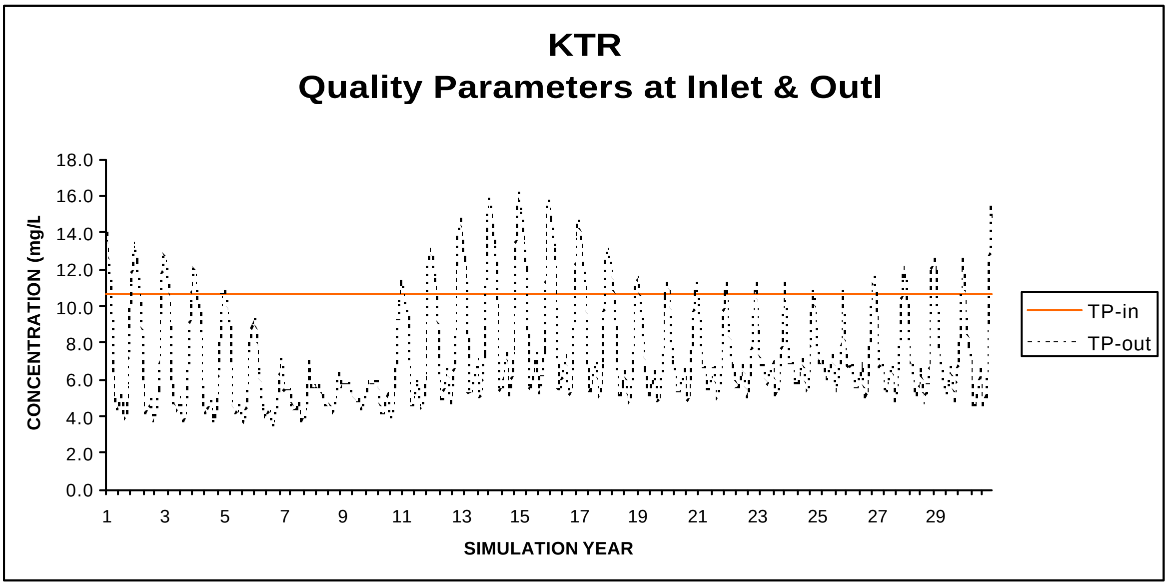


Figure G.22. Projected Total Phosphorus Concentration KTR inflow and outflow, Scenario C(3)

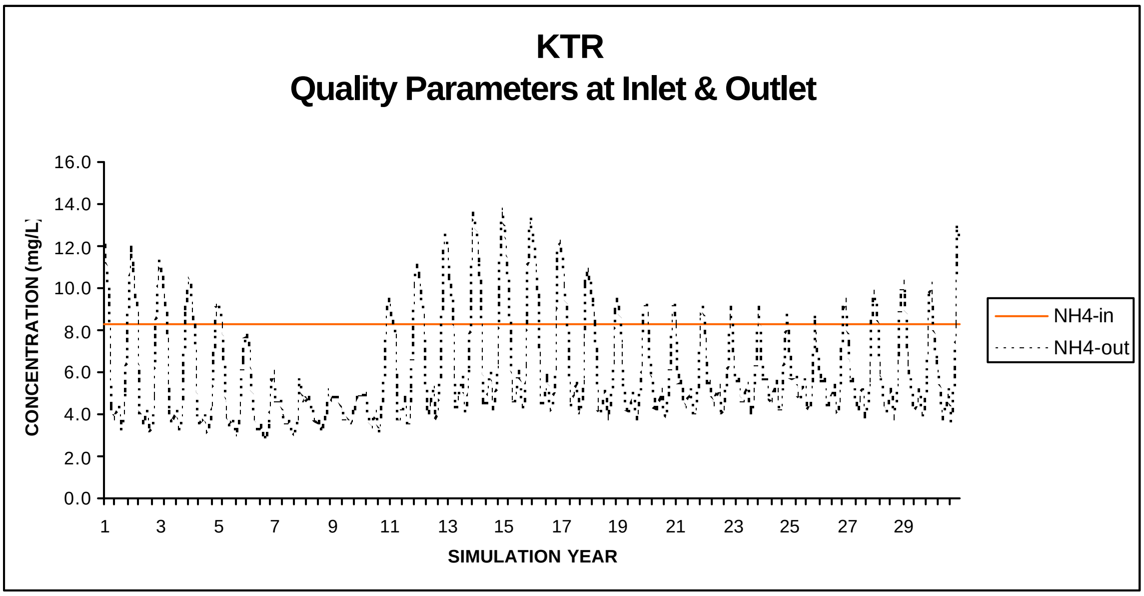


Figure G-23 Projected Ammonium-N Concentration, in KTR Inflow and Outflow, Scenario C(3)

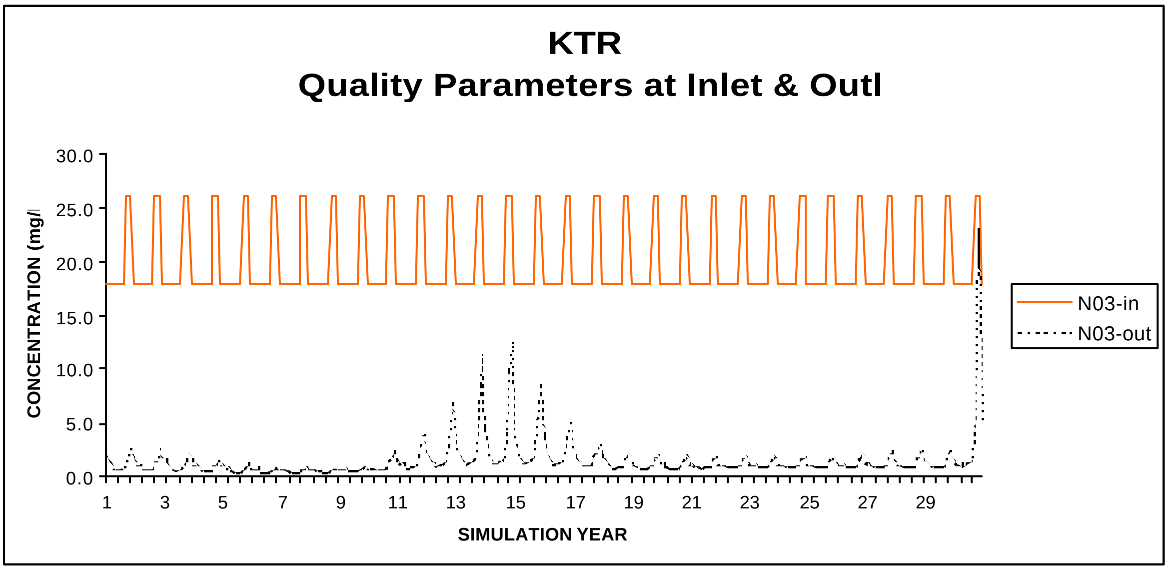


Figure G.24. Projected Nitrate-N Concentration, in KTR Inflow and Outflow, Scenario C(3)

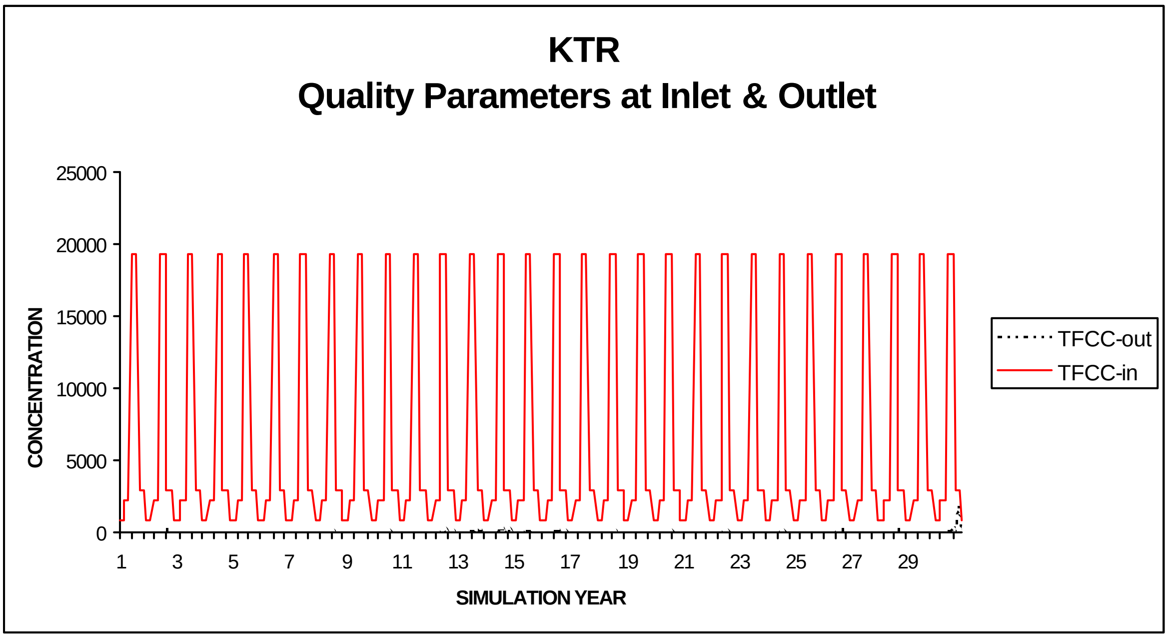


Figure G-25 Projected Fecal Coliform Count Concentration, Station 650, Scenario C(3)

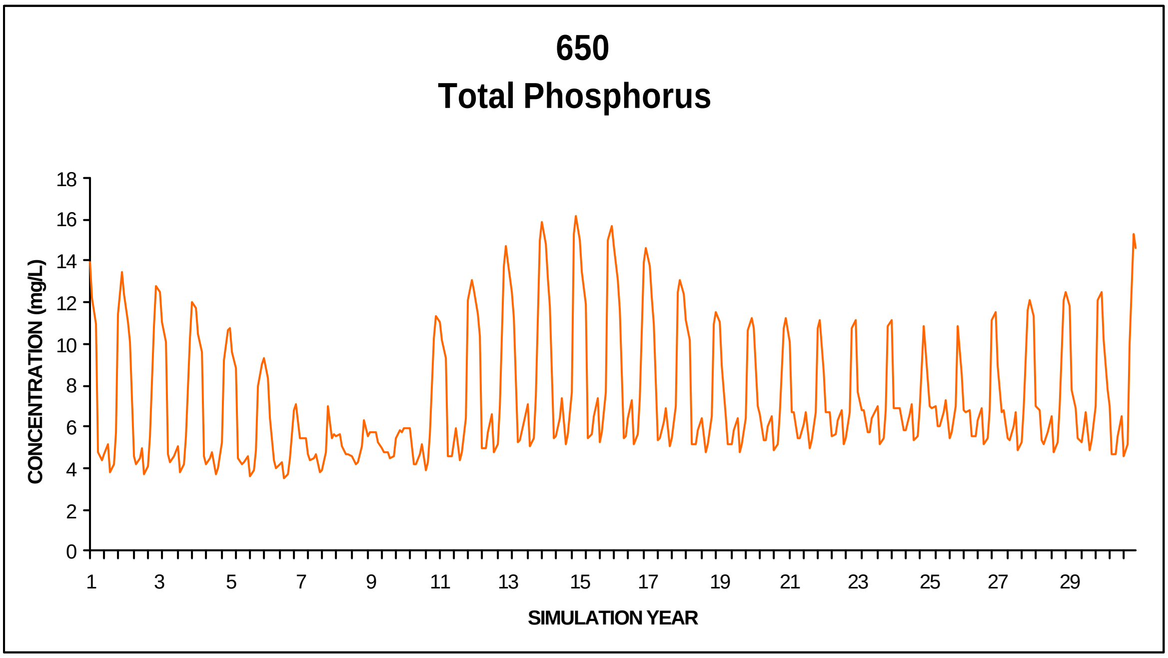


Figure G-26 Projected Total Phosphorus Concentration, Station 650, Scenario C(3)

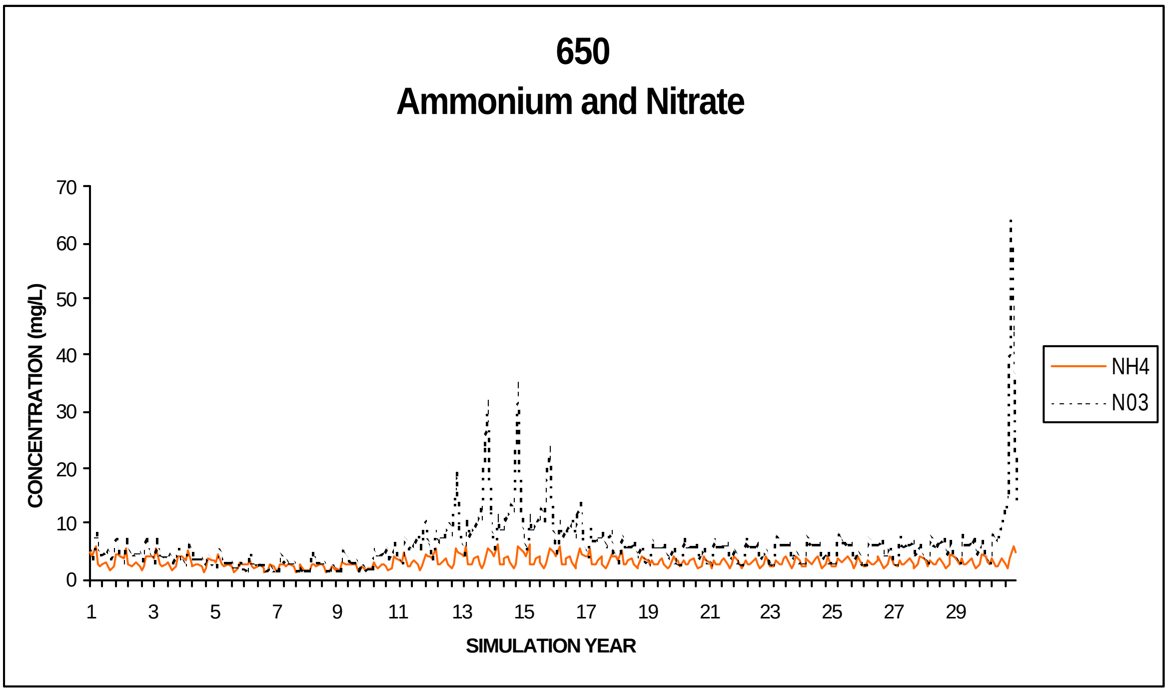


Figure G-27 Projected Ammonium-N and Nitrate-N Concentration, Station 650, Scenario C(3)

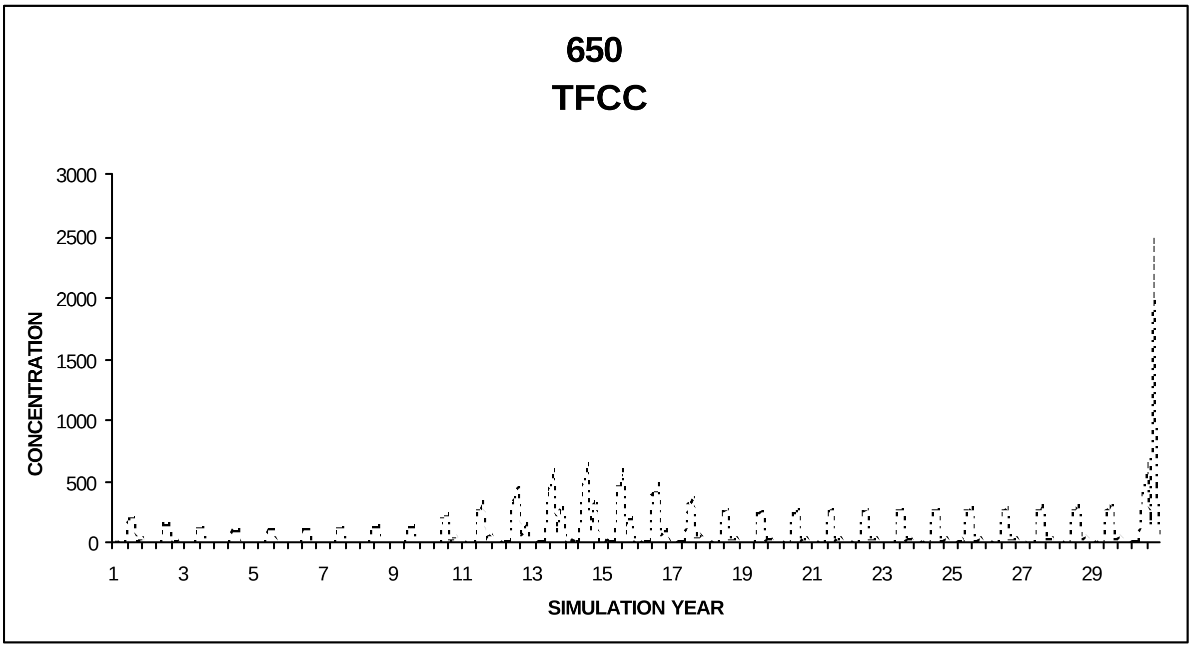


Figure G-28 Projected Fecal Coliform Count Concentration, Station 650, Scenario C(3)